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Sewage Research:

Activated Sludge Oxidations. V. The Influence of Nutrition in Determining Activated Sludge Characteristics. By C. N. Sawyer 3

Growth Promoting Substances in Sewage Sludge. IV. Detection by Biological Agents. By Willem Rudolfs and B. Heinemann 18

Studies of Sewage Purification. XI. The Removal of Glucose From Substrates by Activated Sludge. By C. C. Ruchhoft, J. F. Kachmar, and W. A. Moore 27

Plant Operation:

Properties of Sludge Which Affect Its Discharge Through Twenty-four Inch Pipe. By Willem Rudolfs and Leslie E. West 60

The Development of Sewage Oxidation by a Trickling Filter. By F. W. Gilcreas and W. W. Sanderson 73

The Richmond-Sunset Sewage Treatment Plant By B. Benas 81

II. Laboratory Control of the Richmond-Sunset Sewage Treatment Plant. By K. Fraschina 94

III. Maintenance and Operation of the Richmond-Sunset Sewage Treatment Plant. By R. Sotter 96

Industrial Wastes:

Effect of Cannery Wastes on Operation of Sewage Treatment Plants. By Wm. A. Ryan. Discussion by C. J. Bernhardt 99

The Treatment of Dairy Wastes. By Sylvan D. Montagna 108

Stream Pollution:

Pollution of California State Waters From the Viewpoint of Sports Enthusiasts. By Howard Vernon 114

Pollution of Navigable Waters or Interstate Streams From the Standpoint of the Federal Government or Army Engineers. By Edwin C. Kelton. Discussion by A. M. Rawn 118

Operators' Reports and Suggestions:

Safe Handling of Gas at Sewage Plants. By L. L. Langford 128

Utilization of Sludge Gas for Power Production. By J. F. Hecking 132

Discussion of Paper by Mr. J. F. Hecking, "Utilization of Sludge Gas for Power Production." By B. C. Thiel 141

Maintenance of Sewage Treatment Plant. By Harry J. Krum 143

Safety in Sewage Disposal Plants. By N. W. Hartz 147

Sewer Maintenance. By Harold J. Huber 152

A Sampler for Dissolved Oxygen Tests on Streams and Reservoirs. By A. Adler Hirsch 160

Federation Affairs 163
Federation of Sewage Works Associations Progress Report of Committee for Expansion and Reorganization 164
Federation Board of Control Annual Meeting 165
Federation of Sewage Works Associations. By Chas. A. Emerson 165
Editorial:
Sewage Treatment in Large American Cities 168
Proceedings of Local Associations:
North Dakota Water and Sewage Works Conference Holds Eleventh Annual Meeting 172
Pacific Northwest Sewage Works Association 174
Reviews and Abstracts:
City of Manchester Annual Report of Rivers Department for the Year Ending March 31, 1939 176
The Sewage Treatment Plant at Leiden Netherlands. By D. Boogerd 179
Sewage Treatment at Hilversum (Netherlands). J. F. Groote 180
Report of Board of Review on Sewage Treatment for City of Toronto 181
New Jersey Court Fines Village and Councilmen for Failure to Build Sewage Treatment Works 182
Book Review 184

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Sewage Research

ACTIVATED SLUDGE OXIDATIONS

V. THE INFLUENCE OF NUTRITION IN DETERMINING ACTIVATED SLUDGE CHARACTERISTICS

By C. N. Sawyer

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In the case of activated sludge investigations, as with many other studies, the center of attack has been from the economic angle. Because of the importance of the cost of supplying large quantities of air during the course of treatment, the oxygen requirements of the process have received considerable study during the past decade. These studies have resulted in the development of at least five different methods of determining oxygen utilization by activated sludges.

With the methods available it is possible to make simultaneous studies of the oxygen requirements of activated sludges; and thus it is natural that laboratory investigations of the influence of different food materials on this factor should receive attention.

The reports on the nutrition of activated sludge up to the present have been concerned with what might be termed "instantaneous effects of the addition of specific food materials." Bloodgood [1] has recently reported on oxygen utilization studies made with activated sludge when they were fed synthetic sewage, milk, tomato juice, and corn waste. His results showed a close similarity between the type of oxygen utilization rate curves produced by the synthetic sewage and those by the milk. The rate curves produced by tomato juice and corn waste were quite alike in character but markedly different from those given by the two previously mentioned. Although the B.O.D. loading or amount of food imposed upon the activated sludges was of the same order of magnitude in at least one instance for each food material added, the amount of oxygen and the rate at which it was required were quite different. Bloodgood's results emphasize the advantages to be obtained in economy of plant operation when the character of industrial or trade wastes and their resultant effect on oxygen usage is known.

The author in a previous publication [2] has reported the effect on oxygen utilization when pure substances representing carbohydrates, proteins, and fats were added to domestic sewage and fed to activated sludge from two sources. The influence of these added food materials was found to vary with the kind of activated sludge, depending on whether or not the sludge was capable of oxidizing the nitrogen contained in the substrate. This study showed that both the substrate

and the sludge were factors in determining the quantity of air required to satisfy a given B.O.D. load and showed how the air could best be supplied to meet the changing demands with time.

In a comparison of oxygen utilization rate curves, produced by activated sludges and sewages obtained from four separate sources, Sawyer and Nichols [3] have found the curves produced by the different sludges to be of at least two distinct types. In an attempt to determine some of the factors, important in producing these sludge variations, the work reported in this paper was undertaken.

Experimental Methods

Feeding experiments were conducted in the laboratory on activated sludges obtained from four cities. Portions of each sludge were placed in three-gallon wide mouth bottles. These were fed in a fill-and-draw manner twice daily and kept well aerated to keep the sludge in suspension. The aeration period between feedings averaged approximately ten and one-half hours. The suspended solids in each bottle were maintained close to 1000 p.p.m. This was done by determining the suspended solids in the aeration mixture and wasting portions of it every other day. Sewage was collected principally from one source in City A during the morning hours. During one set of experiments, however, samples were collected at four different points in City A in order to obtain sewages with different characteristics. The oxygen utilization characteristics of the sludges when oxidizing identical sewage substrates were compared weekly in the Oxy-Utilometers.[5] Most of the feeding experiments were conducted over periods of at least three weeks.

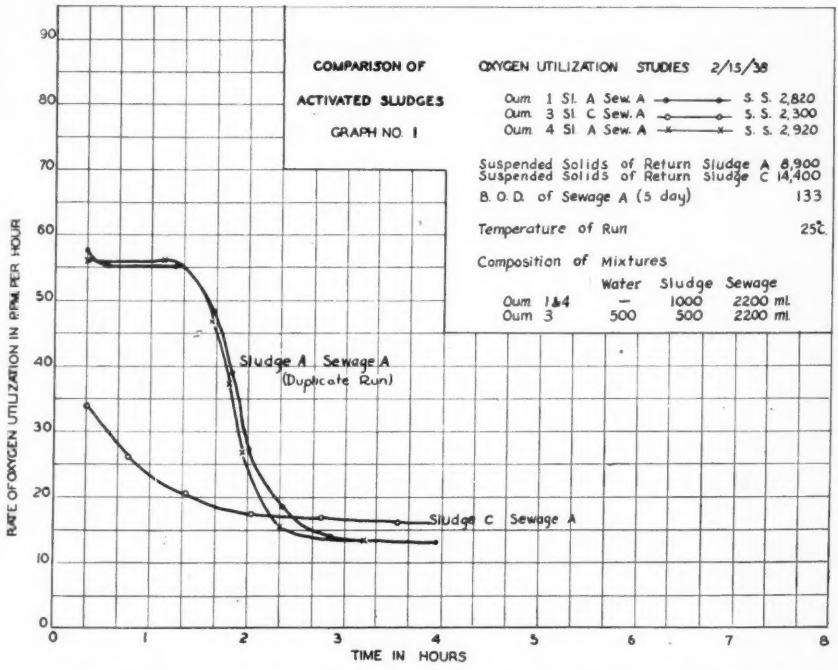
A feeding experiment using two of the sludges mentioned above was conducted in a similar manner at one of the plants at which sludge was obtained. The feeding was performed for a period of three weeks by the plant operator and then the sludges were brought to this laboratory for comparison.

All routine chemical tests were performed by methods outlined in *Standard Methods of Water Analysis* (1936).

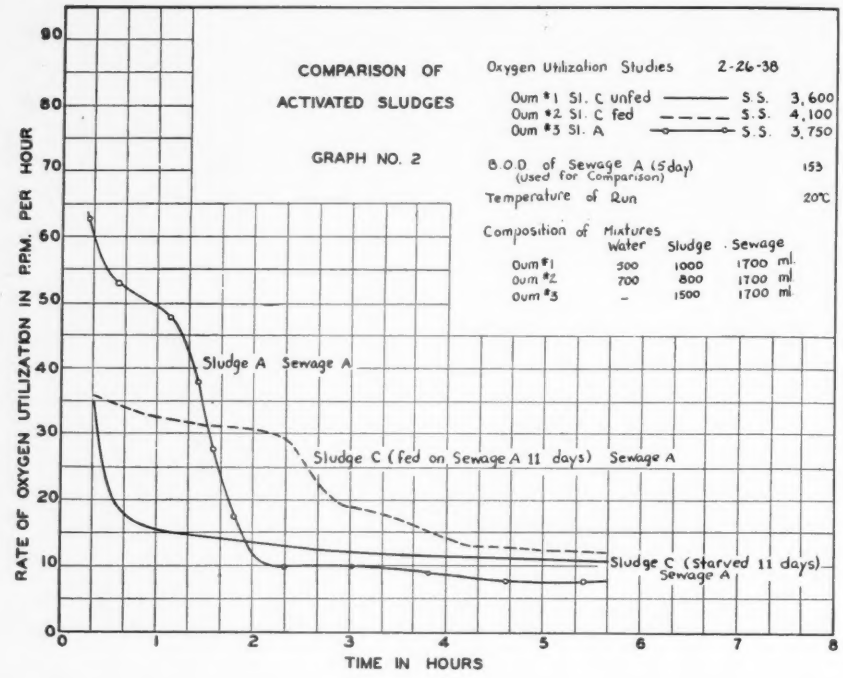
Experimental Results

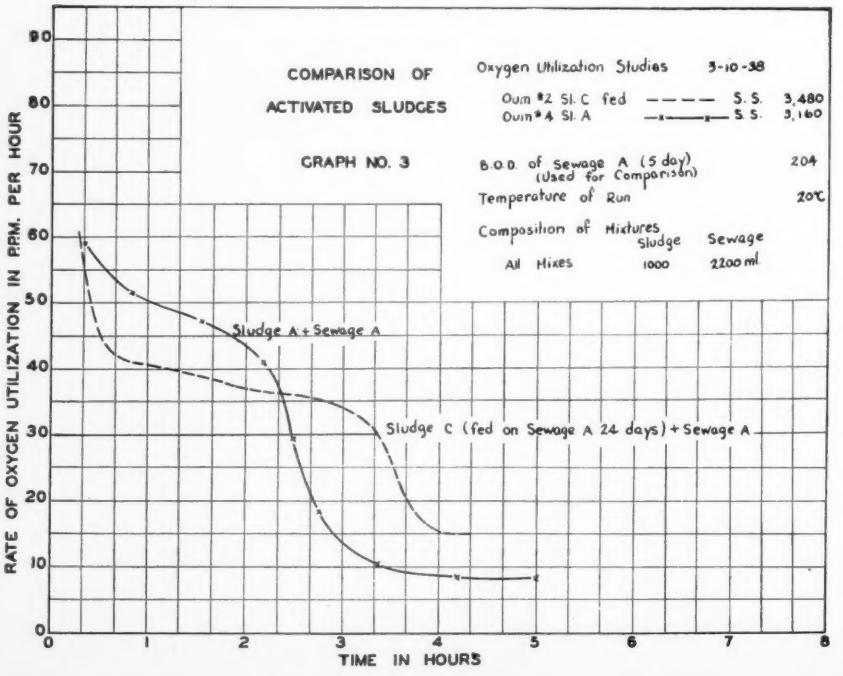
Comparative studies of the oxygen requirements [3] of various activated sludges when oxidizing the same sewage substrate have shown marked variations. One example of such variations is shown in Graph 1 of this paper from which it can be observed that the character of the oxidation rate curve produced by Sludge A is much different from that produced by Sludge C. Inasmuch as the only variable involved in this study was the activated sludge, it was decided to feed Sludge C on the sewage of City A to determine if it would change its characteristics on the new food supply. The supply of Sludge C was divided into two portions, one portion was starved and the other fed on Sewage A twice each day in a fill-and-draw manner. A sample of Sludge A was fed Sewage A simultaneously as a means of comparison.

At the end of four days of feeding one portion and starving the other portion of Sludge C, a comparative run of these sludges with Sludge A was made in the Oxy-Utilometers to determine if any changes had taken place. The results obtained were essentially the same as those shown in Graph 1. The only significant difference was that the curve produced by the starved sludge was slightly lower than that for the fed sludge.



After feeding for eleven days the sludges described above were compared again. The results are shown in Graph 2 from which it can be seen that the general character of the curve produced by Sludge A was about as shown in Graph 1. This was also true of the curve produced by the unfed portion of Sludge C. On the other hand, the portion of Sludge C which had been nourished on Sewage A began to show the same characteristics as Sludge A. The feeding experiment was continued with the fed portion of Sludge C for another thirteen days and on the twenty-fourth day of the experiment another comparison was made. Graph 3 reveals the findings of that comparison. Sludge C was found to have become quite like Sludge A in its oxygen requirements. This result indicated quite strongly that nutrition was an important factor in determining sludge characteristics. However, Sludge C had been brought from a plant operating under winter conditions to warm laboratory conditions, and it was considered that the change in nutrition might not be the sole cause of the change in character of oxygen utilization.


COMPARISON OF
ACTIVATED SLUDGES
GRAPH NO. 2
Oxygen Utilization Studies 2-26-38
Oum #1 Sl. C unfed S.S. 3,600
Oum #2 Sl. C fed S.S. 4,100
Oum #3 Sl. A S.S. 3,750
B.O.D. of Sewage A (5 day) (used for Comparison) 153
Temperature of Run 20°C
Composition of Mixtures
Water Sludge Sewage
Oum #1 500 1000 1700 ml.
Oum #2 700 800 1700 ml
Oum #3 - 1500 1700 ml
Sludge A Sewage A
Sludge C (fed on Sewage A 11 days) Sewage A
Sludge C (Starved 11 days) Sewage A
RATE OF OXYGEN UTILIZATION IN P.P.M. PER HOUR
TIME IN HOURS


COMPARISON OF
ACTIVATED SLUDGES
GRAPH NO. 3
Oxygen Utilization Studies 3-10-38
Oum #2 Sl. C fed S.S. 3,480
Oum #4 Sl. A S.S. 3,160
B.O.D. of Sewage A (5 day) (Used for Comparison) 204
Temperature of Run 20°C
Composition of Mixtures
Sludge Sewage
All Mixes 1000 2200 ml
Sludge A + Sewage A
Sludge C (fed on Sewage A 24 days) + Sewage A
RATE OF OXYGEN UTILIZATION IN P.P.M. PER HOUR
TIME IN HOURS

While conducting studies on the influence of temperature upon the rate of oxidation by four different activated sludges obtained under summer operating conditions, Sawyer and Rohlich[4] found that three of the sludges, A, C, and D, produced curves similar to that of Sludge A in Graph 1. These sludges were found to produce considerable nitrate as is shown in Table I, under zero days of feeding. Sludge E, the other sludge studied, gave an oxidation curve somewhat similar to that of Sludge C in Graph 1 and was found to produce practically no nitrates under zero days of feeding. This difference in oxygen utilization shown by good and poor nitrifying sludges is well correlated with the results shown in a recent paper of this series.[2]

Portions of each of the four sludges were fed on Sewage A for a period of twenty-one days. A comparative study of the character of the oxidation curve and the amount of nitrate produced by each sludge was made at the seventh, fifteenth, and twenty-first days. Results at the seventh day showed that sludges A, C, and D had maintained their original characteristics and that Sludge E was beginning to show a change from its original non-nitrifying character to that of a nitrifying sludge like the others. This is verified in Table I, which shows

TABLE I.—*Nitrate Production in P.P.M. by Various Activated Sludge-Sewage Mixtures at the Beginning and at Different Stages of the Feeding Experiment*

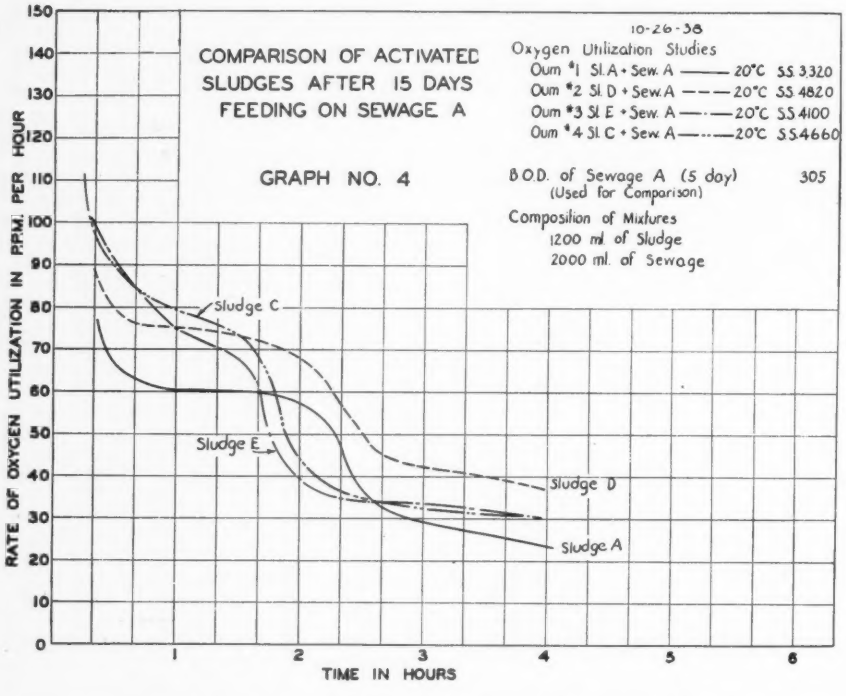
Sludge	Days of Feeding on Sewage A			
	0*	7	15	21
	NO_3-N	NO_3-N	NO_3-N	NO_3-N
A	24	32	19	15
C	12	21.6	17.5	19
D	15	24	21.5	15
E	0.17	4.8	17.5	15

* Sewage used was that obtained at each source when sludge was collected by Rohlich and Sawyer.

that on the seventh day Sludge E produced considerably more nitrate than it did originally. By the fifteenth day, the conversion of Sludge E from a very poor nitrifier to a good nitrifying sludge similar to the others was apparently completed. This is shown in the data of both Table I and Graph 4. Continued feeding of the sludges on Sewage A for another seven days, *i.e.* until the twenty-first day, resulted in a closer similarity of oxygen utilization rate curves produced by the various sludges and approximately the same amount of nitrate in each case.

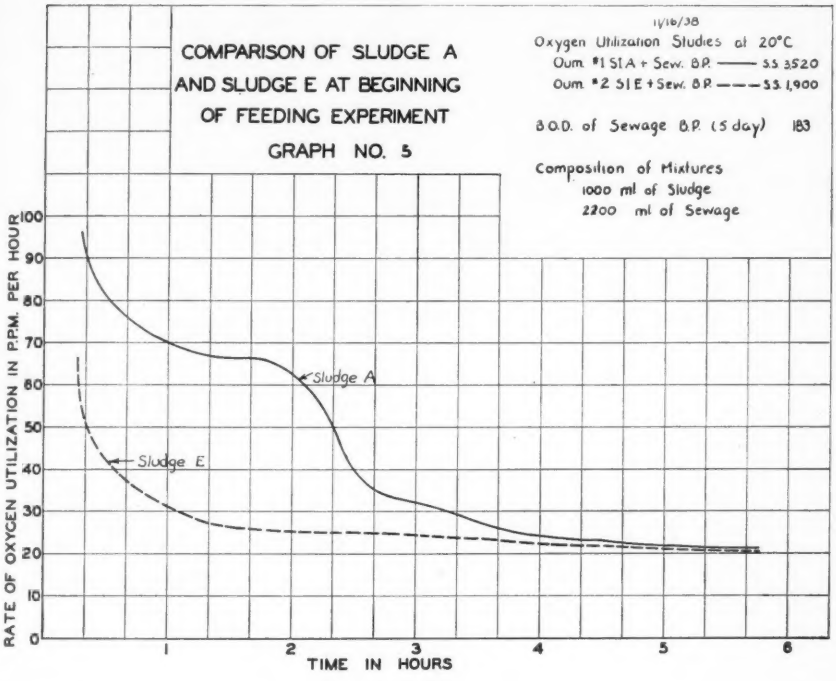
Since Sludge E was collected from the plant under summer operating conditions and was converted from a poor nitrifying sludge to a good nitrifying sludge by feeding in the laboratory on Sewage A, the conversion indicated somewhat more strongly than the first experiment with Sludge C the importance of nutrition in determining sludge char-

acteristics. Nevertheless, it is admitted that conditions imposed in the laboratory are often quite different from those in actual plant operation, and the results obtained might have been affected by increased air supply or some other environmental factor. It appeared that the most conclusive way to prove whether or not nutrition was an important factor would be to have a portion of a good nitrifying sludge such as Sludge A fed on Sewage E in order to see if it would lose its nitrifying ability and be converted to a sludge with characteristics



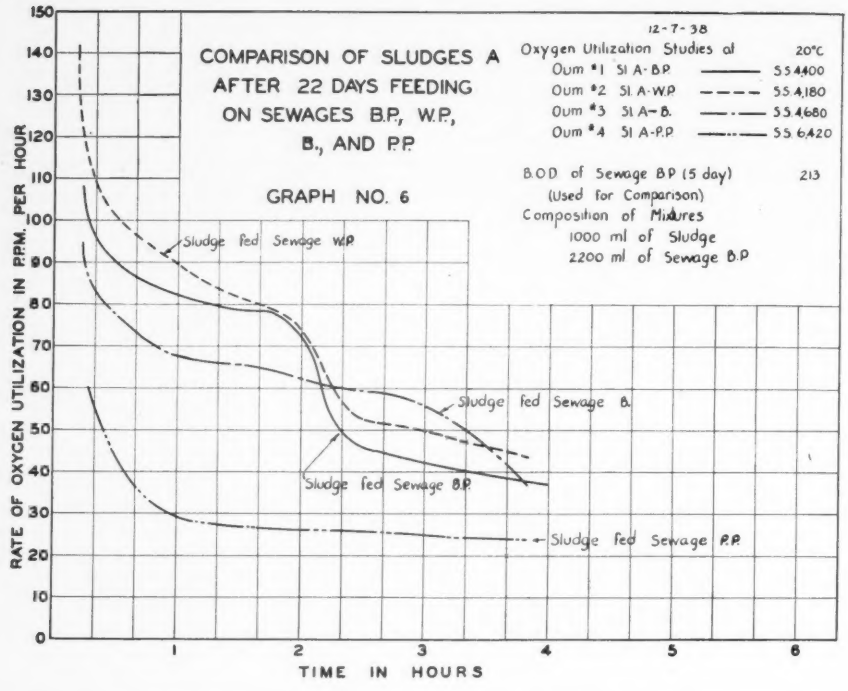
similar to those of Sludge E as collected from the plant. Consequently, arrangements were made to have portions of Sludge A and Sludge E fed in the plant laboratory at the source of Sludge E, using Sewage E for food. At the same time identical portions of the Sludges A and E were fed at this laboratory on Sewage A. Sludges A and E were selected for these experiments because of the marked difference in the type of oxygen utilization rate curves produced by each as shown in Graph 5.

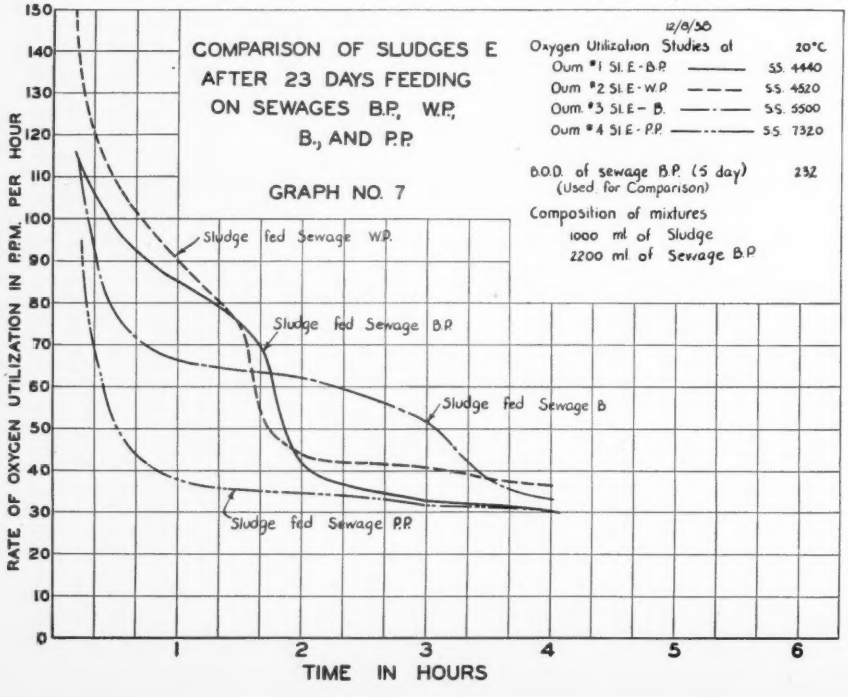
Portions of each sludge were fed in this laboratory on four sewages obtained from four different places in City A. Analyses of the five day B.O.D., ammonia nitrogen, and organic nitrogen, and pH were made daily on the samples from these four sources. The sampling stations were designated as follows, and were so selected that—



1. Sewage W.P. contained domestic sewage only.
2. Sewage B.P. was a composite of all wastes of the city, and contained approximately 10 per cent of chemically treated packing plant waste (animal).
3. Sewage B contained about 25 per cent of the same packing plant waste.
4. Sewage P.P. was the treated sewage from the packing plant.

Weekly comparisons were made on the effect of feeding the four different sewages to the portions of Sludges A and E. The changes resulting were most rapid during the first week, less so during the second, and showed little variation during the third week. Only the final results obtained on the twenty-second and twenty-third days of feeding are shown in Graphs 6 and 7. From Graph 6 it can be seen that the portions of Sludge A fed on Sewages B.P. and W.P. had maintained their original characteristics. The portion fed on Sewage B had changed somewhat and apparently had lost some of its ability to oxidize nitrogen. The portion fed on Sewage P.P. had been converted into a sludge with properties of oxygen usage similar to that of Sludge E at the beginning of the experiment (Graph 5). From Graph 7 it can be seen that portions of sludge E fed on Sewages B.P. and W.P. had developed characteristics comparable to those of the original Sludge A and very similar to those portions of Sludge A fed on these


COMPARISON OF SLUDGES A
AFTER 22 DAYS FEEDING
ON SEWAGES B.P., W.P.,
B., AND P.P.
GRAPH NO. 6
12-7-38
Oxygen Utilization Studies at 20°C
Oum #1 Sl. A-B.P. 55.4400
Oum #2 Sl. A-W.P. 55.4180
Oum #3 Sl. A-B. 55.4680
Oum #4 Sl. A-P.P. 55.6420
B.O.D. of Sewage B.P. (5 day) 213
(Used for Comparison)
Composition of Mixtures
1000 ml of Sludge
2200 ml of Sewage B.P
Sludge fed Sewage W.P
Sludge fed Sewage B.
Sludge fed Sewage B.P.
Sludge fed Sewage P.P.
RATE OF OXYGEN UTILIZATION IN P.P.M. PER HOUR
TIME IN HOURS


COMPARISON OF SLUDGES E
AFTER 23 DAYS FEEDING
ON SEWAGES B.P., W.P.,
B., AND P.P.
GRAPH NO. 7
12/8/38
Oxygen Utilization Studies at 20°C
Oum #1 Sl. E-B.P. 55.4440
Oum #2 Sl. E-W.P. 55.4520
Oum #3 Sl. E-B. 55.5500
Oum #4 Sl. E-P.P. 55.7320
B.O.D. of sewage B.P. (5 day) 232
(Used for Comparison)
Composition of mixtures
1000 ml of Sludge
2200 ml of Sewage B.P
Sludge fed Sewage W.P.
Sludge fed Sewage B.P.
Sludge fed Sewage B
Sludge fed Sewage P.P.
RATE OF OXYGEN UTILIZATION IN P.P.M. PER HOUR
TIME IN HOURS

diets. The portion of Sludge E fed on Sewage B had changed its original character somewhat, but not as much as those fed on Sewage B.P. and W.P. and had gained qualities similar to those of the portion of Sludge A fed on Sewage B. In the case of the portion of Sludge E fed on Sewage P.P., its original characteristics were maintained. Even though the environmental conditions under which all portions of the sludges were fed were approximately the same, some portions of Sludge A underwent changes and some portions of Sludge E also. Feeding on a given diet produced sludges of nearly identical characteristics regardless of the nature of the original sludges. This is borne out by nitrification data shown in Table II and by similarity in color and other physical characteristics, which unfortunately cannot be recorded here.

TABLE II.—*Nitrite and Nitrate Production by Activated Sludges A and E, Fed on Various Diets, During the Runs on the Twenty-Second and Twenty-Third Days*

Diet or Sewage Fed	Sludge A (22nd Day)		Sludge E (23rd Day)	
	NO_2-N in P.p.m.	NO_3-N in P.p.m.	NO_2-N in P.p.m.	NO_3-N in P.p.m.
B.P.	0.19	14.6	22.2	2.9
W.P.	0.72	16.1	3.97	19.2
B	9.0	13.7	20.6	1.8
P.P.	1.30	0.85	4.4	0.09

In regard to color variations, it might be stated that at the beginning of the experiment Sludge A was a golden brown color and that Sludge E had a grayish cast. Upon feeding on a given diet for the three weeks period both sludges gradually became the same in color. The color of the sludges produced on the different diets did, however, differ markedly. Those fed on strictly domestic sewage were of a very dark brown to a black humus like color, those fed on the chemically treated packing plant waste were of a deep tan, while those on the other two diets ranged in between these two extremes depending on the amount of treated packing plant waste which they contained.

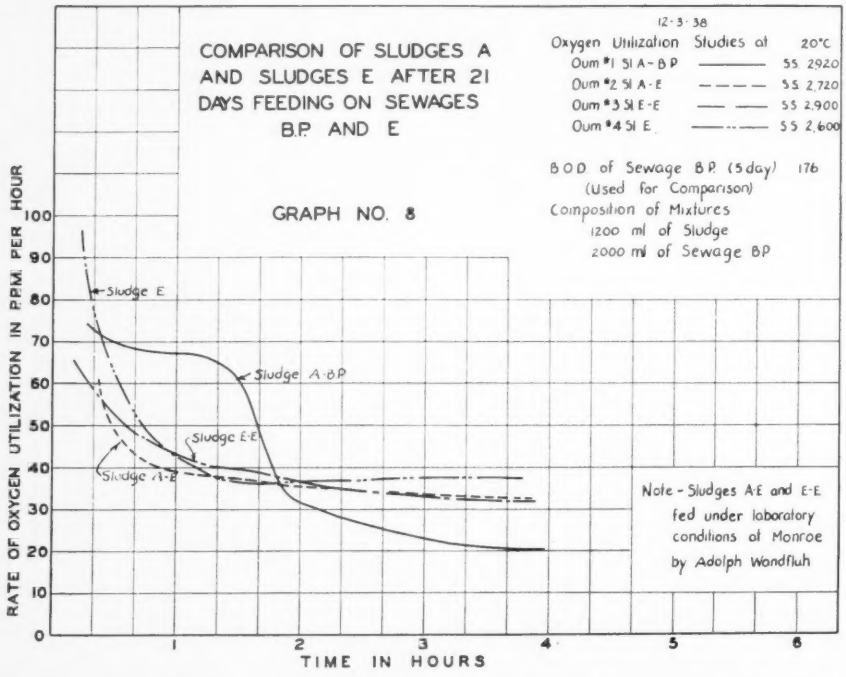
Comparison of the small amount of oxygen used by Sludges A and E fed on Sewage P.P. (Graphs 6 and 7) with the large amount of oxygen used by the other sludges, even though the difference in nitrifying ability is appreciated, might be construed to indicate that the sludges fed on Sewage P.P. had lost some of their ability to stabilize the B.O.D. of added sewage. That such is not the case is seen from the results of B.O.D. determinations made on the effluents at the end of the runs on the twenty-second and twenty-third days as shown in Table III.

The portions of Sludge E and Sludge A (called Sludge E–E and Sludge A–E for differentiation) that had been fed in the laboratory of sewage treatment Plant E on Sewage E were brought to this laboratory for comparison at the end of three weeks feeding. A new sample of

TABLE III.—*5-day B.O.D. Values of Effluents Obtained from Sludges A and E, Fed on Various Sewages, at the End of Runs on Twenty-Second and Twenty-Third Days*

Diet or Sewage	Sludge A B.O.D. of Effluent	Sludge E B.O.D. of Effluent
B.P.	10.4	9.5
W.P.	12.3	13.0
B	19.2	6.3
P.P.	4.8	10.4

return Sludge E from Plant E was also collected and used as a basis of comparison. When making the comparative run to determine the oxygen utilization characteristics of the three sludges, a portion of Sludge A fed on Sewage A (B.P.) was also included, making four sludges in all. The results of this study are given in Graph 8 and show



that the portion of Sludge A which had been fed on Sewage E at Plant E for three weeks had lost its original characteristics and had developed new ones like those possessed by Sludge E. That Sludge E was not materially changed by laboratory feeding on Sewage E is shown by the close similarity of the curves produced by Sludges E–E (laboratory fed) and Sludge E obtained directly from the plant. The results of these experiments appear to minimize the influence of environmental factors in determining sludge characteristics and show definitely that nutrition is a highly important factor.

Now that it is established that the character of the diet is an important factor in determining activated sludge characteristics, we can turn our attention to an analysis of the different sewages used in the feeding experiments in an attempt to find the cause of the changes produced. Since, from a chemical standpoint, the most important differences in the sludges appeared to be their variation in ability to oxidize nitrogen, it would seem most reasonable to consider the carbonaceous and nitrogenous substances present in the sewages used. Daily determinations of the B.O.D. and ammonia and organic nitrogen made on the four sewages fed in this laboratory to sludges A and E are given in Table IV. The analytical data presented in Table VI on

TABLE IV.—*Analytical Data Obtained on Sewages B.P., W.P., B, and P.P. Used in Feeding Experiment with Sludges A and E*

Week P.p.m.	Avg. Daily B.O.D. P.p.m.	Avg. Daily NH_3-N P.p.m.	Avg. Daily Org.$-N$ P.p.m.	Ratio $\frac{\text{B.O.D.}}{NH_3-N}$	Ratio $\frac{\text{B.O.D.}}{\text{Org.}-N}$	Suspended Solids Wasted P.p.m.	
						Sludge A	Sludge E
B.P. Sewage							
1	266	25.3	17.4	10.5	15.3	1100	1060
2	246	27.2	16.7	9.0	14.8	1350	1110
3	298	23.9	17.1	12.4	17.4	1150	1210
Avg.	269	25.5	17.1	10.6	15.8	1200	1130
W.P. Sewage							
1	273	27.3	18.2	10.0	15.0	1280	1240
2	321	46.9	22.9	6.9	14.0	1620	1490
3	323	41.5	24.3	7.8	13.3	1490	1530
Avg.	306	38.6	21.8	8.2	14.1	1460	1420
B Sewage							
1	348	26.9	20.8	13.0	16.7	1800	1620
2	326	28.2	24.5	11.6	13.4	1580	1600
3	362	27.6	25.3	13.1	14.3	1710	1740
Avg.	345	27.6	23.5	12.6	14.8	1700	1650
P.P. Waste							
1	386	25.3	26.9	15.2	14.4	1680	1440
2	369	22.2	29.3	16.6	12.6	1900	1970
3	425	25.0	35.5	17.0	12.0	2840	2950
Avg.	393	24.2	31.7	16.3	13.0	2140	2120

Sewage E were obtained through the courtesy of the Bureau of Sanitary Engineering of the Wisconsin State Board of Health and are believed to be representative of the sewage fed at Plant E.

The averaged data in Table IV, relative to the sewages fed in this laboratory, show variations in the B.O.D. from 269 to 393 p.p.m., in the ammonia nitrogen from 24.2 to 38.6 p.p.m., and in the organic

TABLE V.—*Relative Alkalinity of Sewages Used and Effluents Produced in Feeding Experiments with Sewages B.P., W.P., B, and P.P.*

Source of Sewage	pH of Sewage		pH of Effluent	
	Mean*	Range	Mean*	Range
B.P.	8.05	7.75–8.20	8.15	8.00–8.20
W.P.	8.15	8.05–8.30	8.00	7.80–8.20
B	8.50	8.07–8.70	8.30	8.20–8.35
P.P.	9.40	8.90–9.65	8.15	8.05–8.25

* Mean value of eight determinations.

nitrogen from 17.1 to 31.7 p.p.m. None of these differences, however, can be correlated with the results obtained in the feeding experiment except that the amount of sludge wasted to maintain uniform suspended solids in the mixtures increased with increasing B.O.D. In a comparison of the B.O.D. to nitrogen ratios there is little difference among the four sewages when compared on the basis of organic nitrogen, but when consideration is given to the ratio of B.O.D. to ammonia nitrogen it can be seen that there is quite a wide variation (8.2 to 16.3) and that the sewage which contained the smallest amount of B.O.D. per unit of ammonia nitrogen, *i.e.* Sewage W.P., was the one which produced the most actively nitrifying sludge. (See Table II for nitrification data and Graphs 6 and 7 for oxygen utilization characteristics.) Sewage P.P. which contained the greatest amount of B.O.D. per unit of ammonia nitrogen was the one which gave sludges with practically no ability to oxidize nitrogen, and the other two sewages with intermediate B.O.D. to ammonia nitrogen ratios fell in between the two extreme cases in their respective order.

In Table V are shown the pH values of the sewages used in these experiments.

Inspection of Table VI shows even greater B.O.D. loads per unit of

TABLE VI.—*Analysis of Sewage E as Furnished by the Bureau of Sanitary Engineering of the Wisconsin State Board of Health*

Date 1936	5-day B.O.D. P.p.m.	NH_3-N P.p.m.	Org.$-N$ P.p.m.	$\frac{\text{B.O.D.}}{NH_3-N}$ Ratio	$\frac{\text{B.O.D.}}{\text{Org.}-N}$ Ratio
11–10	403	23.0	16.0	17.5	25.2
11–11	453	18.5	19.0	24.5	23.8
11–12	419	20.0	16.0	21.0	26.2
Avg.	425	20.5	17.0	21.0	25.1

ammonia nitrogen for Sewage E. On this basis it would be predicted that sludge developed on such sewage or fed on it for any length of time would not be of the nitrifying type. Such is actually the case, in fact, not only the samples of sludge fed in the laboratory at Plant E, but all the samples of Sludge E obtained directly from the plant which

have been studied in this laboratory have never shown anything but a trace of ability to oxidize nitrogen.

Discussion

Although the activated sludge process of sewage treatment has been developed and applied extensively during a period in which great advances have been made in the field of animal and plant nutrition, there has been little attempt to correlate or apply this knowledge to this method of sewage treatment. There are, no doubt, several reasons for this delay. Probably the most important one is the tendency of many plant operators to accept with resignation everything which emerges from the contributing sewers. Such acquiescence may be due to indifference of the operator but, more probably, to constant frustration of his attempts to gain equipment, assistance, and cooperation in making a study of his problem with regard to their significance and control. The inadequacy of the routine tests (B.O.D., ammonia N, organic N, etc.) applied in sewage analysis to dietary evaluation has also retarded the application and correlation of knowledge gained in other biological fields. The nature of the routine observations normally performed to determine the relative characteristics of activated sludge, namely color, odor, settleability, and enumeration of the grosser microscopic life are of such a qualitative nature that little information of value can be expected. Of these tests, only the one which determines the settling characteristics of the sludge has found much application and it has become indispensable from an operating standpoint. The variation in color of the activated sludge from plant to plant has been of considerable concern to many people, and has been the basis upon which "good" and "poor" sludges have frequently been judged. On the basis of operating results, there is considerable question of the value of this observation when applied to different plants, but it does, however, appear to have considerable value at a given plant.

In the field of animal nutrition, studies have been made to ascertain the most suitable diets for all animals of economic significance. The constituents of a good diet for one group of animals may be widely different from those for another, but fundamentally, from a chemical standpoint, they are all constituted of the three classes of food materials, namely carbohydrates, fats, and proteins, with a liberal supply of the essential mineral elements in addition. The feeding of animals for prolonged periods on diets that are severely out of balance results in malnutrition and possibly in the development of a "deficiency disease." The remedy most generally applied is, of course, the addition of the deficient material to the diet to bring it back to normal.

In the field of biological sewage treatment, we are dealing with another group of organisms which live upon a food supply which man has chosen to waste. It would be illogical to assume that the principles of nutrition found applicable from the largest to the smallest animals do not apply to the still lower forms of organisms which are so im-

portant in the disposal of wastes without the development of a nuisance. Of what the optimum diet for activated sludge organisms consists no one has so far determined, but no doubt it would be safe to predict that it contains at least some of each of the three classes of food materials and a liberal allowance of the essential mineral elements.

Domestic sewage is probably the most balanced waste of all because of its origin, since man habitually attempts to balance his diet to the best of his knowledge and the "crumbs which fall from his table" are bound to be constituted of all the essential food materials. In this connection it is of interest to bear in mind that the most successful applications of the activated sludge process have been on strictly domestic sewages or on sources of sewage so large that diversification of industries presumably do not produce an unbalanced sewage for treatment. On the other hand, in a small city with a single large industry releasing a strong unbalanced waste into the sewers, the sewage may become so loaded with one particular class of food material that a normal activated sludge will not develop. When the optimum dietary requirements of activated sludge are known, such cities may find relief from their troubles by encouraging the establishment of industries within their jurisdiction which will release wastes of a character to put the sewage back into balance with respect to the nutritional requirements of the sludge. Some study, from a nutritional standpoint, should be given to the present practice of primary clarification, since in most cases the ratio of B.O.D. to ammonia nitrogen and other nutritional characteristics are markedly affected by such treatment. In some cases elimination of the practice may be desirable, while in others more efficient clarification may be advantageous. The disposal of garbage in sanitary sewer systems may well be studied from a similar viewpoint. Undoubtedly, the nutritional characteristics of garbage are quite different from sewage, and, consequently, in some cases may be a desirable addition while in other cases it might tend to throw the resulting sewage still further out of balance and be most undesirable. These avenues of study appear to be the logical lines of attack on the problem. It would seem that any others must first be shown to be justified economically.

Summary

1. Laboratory feeding experiments were conducted at room temperatures with four activated sludges (A, C, D, and E) possessing widely different characteristics and with five different sewages. In all cases, dissimilar sludges fed on a given sewage as a diet gained similar characteristics within a three weeks period.

2. Although the activated sludges were all fed under nearly identical environmental conditions, the character of sludge produced on each diet was distinctly different. On certain diets, sludges which were originally poor nitrifiers became strong nitrifiers, and on other diets, sludges which were good nitrifiers lost the ability and became essentially non-nitrifiers.

3. The variation in nitrifying ability of the sludges fed on the different diets could not be correlated with the B.O.D., ammonia nitrogen, or organic nitrogen content of the food materials when each of these factors was considered individually.

4. The B.O.D. to ammonia nitrogen ratio in the different diets showed a variation from 8.2 to 21.0. Sludges fed on the diet containing only 8.2 p.p.m. of B.O.D. for one p.p.m. of ammonia nitrogen developed the greatest ability to oxidize nitrogen, while the sludges fed on diets containing 16 or more p.p.m. of B.O.D. per unit of ammonia nitrogen lost most of their ability to oxidize nitrogen. Sewages with ratios between 8.2 and 16 gave sludges with intermediate abilities of oxidizing nitrogen which fell into their respective order.

5. The color of the sludges resulting from the feeding experiments was influenced markedly by the presence of a chemically treated packing house waste. The colors of the sludges varied from a dark brown on a diet of domestic sewage to a deep tan on the treated packing plant waste diet.

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GROWTH PROMOTING SUBSTANCES IN SEWAGE AND SLUDGE *

IV. DETECTION BY BIOLOGICAL AGENTS

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In previous papers of this series (1, 2) the presence of various growth promoting substances in sewage and sludge was investigated by chemical determinations of specific compounds or groups of compounds. Determinations of the growth stimulating substances by chemical analyses is handicapped by the lack of suitable methods to determine the small quantities present and the difficulty of working with highly complex organic materials in sewage and sludge which may interfere with the methods of analyses.

Most of the work on assaying various growth promoting substances has been done by using biological methods. These methods do not identify the substance, but are used to measure the response of plants to specific compounds. In sewage and sludge various growth promoting substances are present, so that no specific materials but mixtures of substances responsible for stimulating growth could be measured by biological methods. In the published literature a number of indices and a variety of plants are recorded which have been used to determine the degree and extent of stimulation. Among these are the widely used avena-coleoptile, the pea test, or some similar test. Recently the use of lower plant forms, such as yeasts and molds, has been explored as indicators for the presence of growth promoting substances. For instance, yeasts have been used for the assay of vitamin B_1, which has been reported as capable of promoting the growth of plants. Grace (3) used the quick response of yeast for assaying mixtures of 1- and 2 α-naphthylbutyric acids. Boas (4) used yeasts, *Aspergillus niger* and *Rhizopus nigrican,* for the purpose of detecting growth promoting substances in various parts of plants. Extracts of the plant organ were added in varying quantities to a nutrient medium which was then inoculated with a determined number of cells of the test organism. After a period of incubation determinations were made of the number of cells in the control (no extract) and the medium containing plant extract, thus giving an indication of growth-stimulating materials present when higher counts were obtained with the medium containing plant extracts. Rippel (5), using the nutrient medium of Boas modified slightly, devised a unique method for determining growth promoting stimulation in the nutrient medium to which stimulatory materials were added. Using the yeast *Saccharomyces cereviseae* in a medium containing ammonium sulfate as a source of nitrogen, there will be a

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gradual reduction in pH value as the ammonium ion is utilized. He found a relationship between the pH values, after twenty-four hours incubation of the test organism, and the numbers of cells present. The lower the pH value obtained, the greater the number of cells and the greater the growth stimulation.

Using the method of Rippel and adjusting it to our purpose various sewages and sludge extracts were tested for their ability to stimulate the growth of *Saccharomyces cereviseae.*

Methods and Material

The adopted method used, the precautions taken, the preparation of the sewages and sludges, the measurement of growth stimulation and the amounts of growth promoting material added to the nutrient media were briefly as follows:

Medium.—The nutrient medium used was that of Boas (4) as modified by Rippel (5). It was constituted as follows:

Constituent	Grams per 100 c.c.
Dextrose	5.0
KH_2PO_4	0.18
K_2HPO_4	0.15
$MgSO_4$-$7H_2O$	0.1
$(NH_4)_2SO_4$	0.2
$CaCl_2$-$6H_2O$	0.05
NaCl	0.05
Na_2SO_4-$10H_2O$	0.05
H_3BO_3	0.0002
$ZnSO_4$	0.0002
$MnSO_4$	0.0002
$FeCl_3$	0.0002
Triply distilled water to volume	
pH—approximately 6.78	

Great care must be exercised in obtaining chemicals of the highest purity. A satisfactory dextrose could not be obtained, and it was necessary to prepare one by repeatedly extracting a chemically pure dextrose with ether and alcohol and evaporating to dryness.

For enumerating the number of yeast cells in the liquid medium, two grams of shredded agar per 100 c.c. medium was added to the nutrients already listed and pour plates (Petri dishes) were used. In the agar medium, unpurified dextrose was used.

Glassware.—It was necessary that all glassware used be scrupulously clean in order to avoid interference with the tests from substances adhering to the glass. The glassware was subjected to the action of cleaning solution in the usual manner, then rinsed in succession with dilute sodium hydroxide, dilute hydrochloric acid and three or four times with distilled water.

Culture.—A culture of *Saccharomyces cereviseae* (bottom yeast) was obtained and cultured on ordinary wort agar. When ready to be

used as a test organism, a 48 hour culture was shaken thoroughly to distribute the cells and a loopfull (1 mm.) removed to a sterile, 25 c.c. dilution blank. This was shaken thoroughly and one drop inoculated (by means of a sterile 1 c.c. pipette) into the solution to be tested. The numbers of organisms in the inoculum were determined by agar plate counts.

Incubation.—The test solutions were incubated for 48 hours at 32° C. before the pH value or the number of cells present were determined.

pH Value.—The pH value of all test solutions was determined by means of a Beckman potentiometer.

Sterilization.—The nutrient medium was sterilized, after addition of the sewages or sludge extracts, in flowing steam on three successive days for a period of one hour each day. Comparisons were made of media sterilized by flowing steam and under pressure.

The agar medium for enumerating the number of yeast cells in the media tested was sterilized in the autoclave at 15 pounds pressure for 15 minutes.

Preparation of Sewages and Sludges.—The sewages and effluents were added in varying quantities to the liquid nutrient medium without further treatment. The nutrients were prepared in such concentrations as to give the same final concentration in a volume of 10.0 c.c. prior to sterilization. For example, 2.5 c.c. of sewage was added to 7.5 c.c. of nutrient medium containing sufficient nutrients to give the amounts indicated in a volume of 10.0 c.c.

Water extracts of the sludge were made by placing 3 grams of dried sludge in a flask to which was added 25 cc. distilled water. The flask was stoppered and placed in a 65° C. water bath for one hour. The liquor was then decanted carefully and aliquots used to test for growth promoting properties.

Ether extracts of the sludges were made by placing 3 grams of dried sludge in a flask to which was added 25 c.c. of ethyl ether, purified according to the method of van Overbeek (6). The extraction was carried out in a stoppered flask for 24 hours at 4° C. The ether was then removed by evaporation and the residue taken up in 25 c.c. of warm (65° C.) distilled water. Several other extracting agents have been used.

Measurement of Growth Stimulation.—It has been mentioned above that Rippel (5) found that a relationship existed between the number of cells present in his synthetic medium and the extent to which the pH value was lowered, thus indicating directly the amount of stimulation in growth brought about by various substances through the increased number of yeast cells present. An example of the relationship existing is given in the following calculation:

At a pH value of 4.45, counts on agar medium showed that there were 660,000 cells present.

4.45 + 5.82 (log 660,000) = 10.27
10.27 — 3.28 (pH of another medium being tested) = 6.99
antilog 6.99 = 9,770,000 cells present in medium of pH 3.28.

These results were checked experimentally by Rippel and the calculations were found to be valid. Our experimental work also showed this relationship to hold. In the results presented, the numbers of cells in the test medium are not given, but the pH values and the extent to which they were lowered give an indication of the degree of growth stimulation caused by the various sewages and sludges. It should be kept in mind that with each unit drop in pH value the number of cells present increase in a logarithmic fashion.

Amount of Growth Promoting Material Added.—Varying amounts of sewages and sludge extracts were added to the medium, since it is known that the effect of growth stimulation by various substances depends upon the concentration in which they are present. Too great a concentration may have a depressing effect. It was thought desirable to determine, if possible, the optimum concentration of the sewages and sludges to give the maximum stimulation.

Results

Relation Between pH Values and Number of Cells.—For the determination of the relation between pH values of the medium and the growth of the test organisms the pH values of the medium were determined at the beginning and after 48 hours. The change in pH values was brought about as a result of the utilization of nitrogen from ammonium sulfate. The test organisms were the yeast *Saccharomyces cereviseae* and the mold *Aspergillus niger.* Some results obtained, using various sludges extracted with water and ether, are presented in Table I. The extracts consisted of 2 grams dried material in 50 c.c. of liquid. The ether extracts were concentrated and the solvent removed before adding 100 c.c. of the medium to be tested. A 1 c.c. portion of the water extract was added to 10 c.c. of the medium to be tested. Although certain discrepancies may be found in the results, they correlated rather well. The discrepancies appear greater than they actually are, because the pH values recorded are not accurate enough. Other results given in the tables are closer.

Growth of the yeast was stimulated to a greater extent by water extracts of the various sludges than by the ether extracts. More growth stimulating substances appeared to be present in fresh solids than digested sludge. The effect of water extracts from heat dried sludge was considerably less and more like fresh activated sludge. Using the mold as an index again, water extracts caused greater stimulation than ether extracts, with fresh solids leading.

Effect of Sterilization.—A comparison was made of the effect of the method of sterilization on the amount of growth stimulation exerted on yeast cells when various sludge extracts were added to the nutrient medium. Ether and water extracts of the sludges were used

TABLE I.—*Relation Between pH Values and Number of Cells*

Source	Extract	*S. cereviseae*			*A. niger*		
		pH	No. Cells	Increase Factor	pH	No. Cells	Increase Factor
Act. Sludge	Water	4.6	467,700	25	4.4	342,000	62
Fresh Solids	Ether	3.2	11,750,000	630	4.0	549,500	100
	Water	3.2	11,750,000	630	3.0	5,495,000	1000
	Carotene	4.7	371,500	20	4.0	549,500	100
Digested Sludge	Ether	6.0	18,620	1	5.5	17,380	3
	Water	4.0	1,862,000	100	3.7	1,096,000	180
Spray Dried Solids	Ether	6.0	18,620	1	5.8	8,710	1
	Water	4.5	588,800	32	3.5	1,738,000	300
Sewage	1 c.c.	4.1	1,479,000	79	4.1	436,500	79
Control—nothing added	—	6.0	18,620	1	6.0	5,495	1
Control—uninoculated	—	6.7	0	0	6.7	0	—

and media containing these extracts sterilized in flowing steam and by steam under pressure. The results are presented in Table II.

The results indicate that sterilization of the medium in flowing steam invariably resulted in a greater stimulation of the yeast cells than when sterilized in the autoclave. The ether extracts of the sludge did not result in as good stimulation as the water extracts. The medium to which ether extracts had been added, and which was steri-

TABLE II.—*Comparison of pH Values Obtained From the Growth of* S. cereviseae *in Nutrient Medium, Containing Sludge Extracts, Sterilized in Flowing Steam and by Steam Under Pressure*

Amount of Sludge Extract Added C.c.	Sterilized in Flowing Steam					Sterilized by Steam Under Pressure				
	Digested Spray Dried	Fresh Solids	Activated Sludge	Digested Vacuum Dried	Control—No Extract	Digested Spray Dried	Fresh Solids	Activated Sludge	Digested Vacuum Dried	Control—No Extract
	Water Extracts of Sludge					Water Extracts of Sludge				
1.0	5.03	3.39	3.12	3.65	5.60	5.89	4.89	4.61	5.28	5.68
2.0	4.48	2.99	3.20	3.90	—	5.40	3.28	4.08	4.87	5.80
3.0	4.50	2.99	3.20	3.89	5.90	5.83	4.63	4.12	4.71	5.80
4.0	4.51	3.13	4.25	3.79	—	4.85	4.50	4.28	4.61	5.65
5.0	4.92	3.11	4.30	3.51	5.60	4.91	4.08	5.41	4.22	5.55
	Ether Extracts of Sludge					Ether Extracts of Sludge				
1.0	5.56	5.40	5.10	5.31	5.60	No Growth	No Growth	No Growth	No Growth	5.68
2.0	5.47	4.63	5.02	5.48	—					5.80
3.0	—	5.15	4.09	4.38	5.90					5.80
4.0	—	4.87	4.64	4.45	—					5.65
5.0	5.87	5.06	4.23	4.95	5.60					5.55

lized in the autoclave, did not permit any measurable growth of the yeast cells.

Of the individual sludge extracts, that from fresh solids gave the best stimulation when water was used as the extractor. With ether extracts relatively the best results were obtained with those from activated sludge.

It is evident that vary amounts of extract gave different degrees of stimulation. Frequently the difference in pH value was so small as to be within the limits of experimental error. Sometimes a difference of as much a 1 pH unit or more was distinguished, indicating a difference in growth stimulating properties.

Sewage and Sludge From Different Sources.—A comparison was made of the amount of stimulation on the yeast cells caused by different amounts of sewages and sludge extracts from various treatment plants. The medium was sterilized in flowing steam in all cases. Only water extracts of the sludges were used. The results are presented in Table III.

TABLE III.—*Comparisons of pH Values Obtained From the Growth of* S. cereviseae *in Nutrient Media Containing Sewage or Sludge Extracts in Decreasing Concentrations*

Source of Sewage and Sludge Extract	pH Values of Cultures		
	Amount of Liquor Added in C.c.		
	2.5	5.0	10.0
Plainfield			
Raw Sewage	3.93	4.67	4.18
Primary Settling Tank Supernatant	3.75	4.68	4.21
Primary Settling Tank Effluent	3.39	3.60	4.11
Trickling Filter Influent	3.95	4.04	4.10
Trickling Filter Effluent	3.68	4.41	3.28
Final Tank Effluent (Chlorinated)	3.49	4.20	3.62
Fresh Solids	3.02	3.11	3.86
Digested Spray Dried Solids	4.52	4.92	4.06
Bernardsville			
Raw Sewage	3.48	3.48	3.35
Final Effluent	3.70	3.60	3.02
Aeration Tank Liquor	3.43	5.60	3.65
Return Activated Sludge	5.78	5.60	4.25
Highland Park			
Raw Sewage	3.87	3.21	3.40
Primary Settling Tank Supernatant	4.21	4.28	4.38
Tank Effluent (Chlorinated)	3.30	5.67	3.38
Digestion Tank Supernatant	3.79	4.06	4.64
New Brunswick			
Raw Sewage	3.57	4.92	4.60
Clarifier Supernatant	3.70	5.98	4.75
Final Effluent (Chlorinated)	3.70	4.00	3.45
Digestion Tank Supernatant	3.45	3.79	4.08
Chemical Vacuum Dried Sludge	3.94	3.51	4.06
Control	5.80	5.85	5.85

The results show that the quantities of the extract added, or the gross concentrations of the growth stimulating substances, are important factors in determining the relative effect of the materials. It is of interest that in general the higher concentration of sewage, effluents or sludge extracts added produced a greater effect than the same amount of extract in a greater dilution.

It appears therefore, that there is a minimum concentration of growth promoting substances to stimulate *S. cereviseae.* Of the sludges, fresh solids extracts produced best results. Settling of fresh sewage appears to reduce the effect, but settling of stale sewage appears to remove less of the growth promoting substances. It is of particular interest that chlorination as practiced at the various plants does not destroy or reduce the growth stimulating properties for yeast cells present in the sewage effluent.

Discussion

When *S. cereviseae* is used as a test organism for determining the effect of growth stimulating substances present in sewages and sludges a distinction must be made between growth promotion as characterized, for instance, by cell elongation, and by an actual increase in the number of cells. Many investigators have claimed cell elongation to be a result of growth promotion in plants, whereas the yeast cells used as test organisms would respond to growth stimulation by an increased rate of multiplication. It is clear that one of the limitations of the method used is the inability to apply the results to plants, and another limitation is the inability to identify the specific substance responsible for stimulating growth. When pure substances are used for trial the latter objection does not hold, but since it has been shown previously that a number of different growth promoting substances are present in sewage and sludge the shortcomings of the method are apparent. It has been shown that there are several substances which can stimulate the growth of yeast cells as well as plants. The nutrient media contained the minerals necessary for the growth of the yeast cells, but there is also the possibility that small amounts of minerals present in the sewage or sludge extracts affected the growth of the cells.

Growth stimulation of yeast cells and plants is caused by a variety of organic and inorganic substances. One of the least known substances for stimulating the growth of yeast cells is vitamin B_1. This substance has also been shown to be of value in stimulating the growth of plants (7). Attempts to determine chemically the presence of vitamin B_1 in sewage and sludges has not been very successful thus far, but it is believed to be present. Even though all other growth promoting substances were removed or destroyed by the various treatment processes, and vitamin B_1 remained, growth stimulation of the yeast cells would be pronounced. It is evident therefore that there is the possibility that in testing various sewages and sludges with yeast cells important substances for plant growth will not cause stimulation in

yeast growth. The limitations of the method used are emphasized to avoid the drawing of unwarranted conclusions. Extensive testing with various plants will be necessary before the value of sewage and sludge for plant growth can be accurately and adequately determined.

A noticeable difference was observed in the ability of the medium containing sludge extracts to stimulate growth when sterilized under different conditions. The poorer results obtained when the extract was subjected to steam under pressure were probably due to a change or destruction of some of the active principles responsible for stimulating growth. The failure of ether extracts to give as good growth stimulation as water extract may be due to the nature of the extracted materials, which are soluble in ether but not subsequently soluble in water and the nutrient medium. It is also possible that substances which inhibit growth were extracted with ether. Various other extracting substances have been tried, mostly different solvents. These questions are of considerable importance if specific or groups of growth promoting substances are to be extracted and concentrated, with waste products as their sources.

Comparing water and ether extracts of sludges, the water extracts produced the best stimulation. Of the sludges tried, fresh solids was the best source. The air dried, dewatered or heat dried sludges had lost or greatly reduced their growth promoting substances, or had them removed or fixed during the processes. The fact that fresh activated sludge and oxidized effluents retained in part their growth stimulating power for yeast cells, together with the findings published in previous papers that certain specific growth promoting substances disappear, would indicate that other, not yet identified, or specific substances shown to be present, were of greatest importance for yeast cells.

With the sewages and sludge extracts, fairly wide concentrations were used in these studies. It is probable that more extensive study of the individual substances, using concentrations within smaller limits as well as combinations of specific substances would show several points of maximum and minimum stimulation.

Summary

A study was made of the use of a yeast, *Saccharomyces cereviseae,* as a test organism for detecting growth promoting substances in sewages and sludge extracts. The method of sterilizing the medium containing the stimulatory substances affected the results. Best results were obtained with intermittent sterilization. Ether extracts of the sludges gave poorer results than water extracts. Of the sludges fresh solids gave the best results. Oxidation reduced the effect, but chlorination of the effluent did not deter the action of the growth promoting substances responsible for stimulation of yeast cells. Concentration of the sewages and sludge extracts was important in determining the maximum growth stimulation. The use of yeast as a test organism is limited, because various growth promoting substances affect cell elonga-

tion as well as the number of cells and the effect of certain specific growth stimulating substances may overshadow others of greater importance in plant growth.

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STUDIES OF SEWAGE PURIFICATION

XI. THE REMOVAL OF GLUCOSE FROM SUBSTRATES BY ACTIVATED SLUDGE

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In a previous paper [1] of this series, the sewage organic matter adsorption, removal and oxidation characteristics of activated sludge were studied. The very high rate of removal of the organic matter of sewage by the sludge and the portion of this removal which could be accounted for by biochemical oxidation was determined. From 2.5 to 30 per cent reduction of the total carbonaceous oxygen demand (L value) of the substrate was accomplished by biochemical oxidation in the first 30 minutes of the process. The remarkable similarity between the purification accomplished by the biologically simple pure-culture zoogleal sludge and the normal activated sludge was noted.

In these studies synthetic sewage containing true colloidal and soluble organic material only, and domestic sewage containing organic material in all states of dispersion, were used. It has been shown that only about 6 to 10 per cent of the organic material contained in domestic sewage is present in true colloidal form and that roughly 33 to 44 per cent may be present in true solution.[2, 3, 4]

Because of the large portion of organic material present in true solution in sewage it is pertinent to study the rates of removal of such material by activated sludge. The rates of removal of non-electrolyte solutes from substrates by the activated sludge process have not been extensively studied under controlled conditions. It was, therefore, decided to study this phenomenon and to use the simple carbohydrate glucose as a test material. Glucose was selected because of the interest in glucose as a cause of sludge bulking, also because its removal can readily be followed directly, and finally because of the ease with which it can be used for energy by bacteria. Kendall [5] states that no case has been recorded of a bacterium which can utilize any carbohydrate that will not utilize glucose also, and there are organisms which do not utilize any carbohydrate except glucose for energy requirements.

In the present study the rates of removal of glucose obtained with normal activated sludge, as taken from an experimental plant, and pure culture zoogleal sludge have been compared. The pure culture zoogleal sludge consists of the flocs formed by a strain of bacteria isolated from normal activated sludge. The isolation of these bacteria and the development of the pure culture sludge have been described by Butterfield.[6] The rates of removal of glucose and sewage organic matter by activated sludges have also been compared. The influence of sludge concentration, temperature and pH upon the glucose removal rate have

been studied. The effect of other factors such as agitation without oxygen, prolonged reaeration, supplemental feeding and chlorination of activated sludge upon the glucose removal rate also has been determined.

Review of Literature

The theory of removal of dispersates of larger than colloidal size by coagulation or condensation on the surface of the sludge particles is readily acceptable. This suggests that the mutual coagulation theory proposed by Baly [7] and frequently reviewed in the literature [8, 9, 10, 11] may be necessary only to explain the removal of the rather small proportion of colloidal organic matter present in the sewage. Baly concluded that lowering the pH of the system to 6.5–6.0 should promote the efficiency of the process. Lumb [8] cited experiments to show the advantage of lowering pH, but Nesmehanoff's [12] experiments in which the pH was lowered to slightly under 6.0 resulted in a decrease in the activity of the sludge and Mohlman [11] states that Baly's suggestion has not been put to practical use.

In any case, the organic materials in solution which include electrolytes and non-electrolytes are not removed from the dispersions medium by the above coagulation or electro adsorption mechanisms. Theriault [13, 14, 15] proposed a biozeolytic theory for the removal of ions of solutes and stated that adsorption of ammonia, amino acids, lignoproteins and related organic constituents could be explained in terms of base exchange.

Theoretically, this leaves the non-electrolyte solutes as the only organic components of sewage whose removal could not be explained upon the basis of one of the several rapid physico-chemical mechanisms conceivably present and active in the activated sludge process. To remove the non-electrolytic solute it is necessary to fall back upon a biophysical-chemical mechanism such as direct cell action or, as Buswell [16] has termed it, bioprecipitation.

The flocs of activated sludge consisting of zoogleal bacteria described by Butterfield [6] and Dienert [17] are heterogenous systems involving enzymic colloids and solutions of cellular materials. Consequently the reactions of these systems upon substrate are also biophysical-chemical. In this case the reaction velocity would seem to be dependent upon the quantities of the biological agents present to activate the reaction. Butterfield and Wattie [18] have shown that the immediate rate of biochemical oxidation of a substrate is proportional to the initial bacterial population. The maximum hourly rate of oxidation for a given substrate was obtained with the maximum number of organisms (10,000,000 per ml. in their experiments) present at the start. This maximum hourly rate became lower and required a longer time to attain as the initial number of bacteria that were present to activate the reaction became smaller.

The bacterial dissimilation of glucose has been extensively studied. Thaysen and Galloway [19] have ably reviewed the work in this field and

their views are briefly summarized here. The mechanism of glucose dissimilation is generally accepted to depend upon the activation of hydrogen atoms in the glucose molecules and their subsequent removal by hydrogen acceptors according to the theory of Wieland.[20] The molecule containing the activated hydrogen (glucose in this case) is termed the hydrogen donator and the oxygen or other hydrogen absorbing molecule or molecule radical, the hydrogen acceptor. The living plasma, or enzymes produced by the plasma, act upon the molecule of glucose in the substrate in which the plasma is suspended. This makes a transfer of hydrogen possible. According to this theory the function of oxygen has been reduced to that of the hydrogen acceptor. This function it shares with numerous other substances such as methylene blue, litmus, nitrates, etc. The reaction between the hydrogen donator and the hydrogen acceptor is considered an oxidation-reduction reaction. Although the oxygen may function as a hydrogen acceptor without preliminary activation, some authorities favor the view that an activation is necessary before oxygen becomes capable of combining with activated hydrogen.

Glucose is first esterified into monophosphoric esters after which it is decomposed by the living cell, according to the mechanism described, into compounds containing less than six carbon atoms. The course of the decomposition and final products formed depend upon the hydrogen activating properties of the organisms involved in the system. Kluyver and Donker[21] have reduced the fermentation activities of micro-organisms to eight types.

The type of glucose fermentation or dissimilation that takes place in activated sludge has not been adequately studied. Butterfield[6] reported that the zoogleal bacterium isolated from activated sludge grew well in the presence of glucose in nutrient broth but that no gas was formed and, as evidenced by changes in pH, no acid was produced. Heukelekian[22] added 1000 p.p.m. of glucose to activated sludge suspensions under mechanical agitation and found that less than 10 per cent of the glucose was removed in an hour. He concluded that as biological action could not be precluded, this removal could not be ascribed to adsorption. Seiser[23] experimented with glucose as a nutrient for activated sludge and concluded that when glucose was fed with asparagin twice as much glucose was removed by adsorption as was removed by biological decomposition.

A very serious case of sludge bulking occurred at Des Plaines River activated sludge plant in 1927 and Morgan and Beck[24] found a large quantity of glucose (10,400 p.p.m.) in a portion of the sewage. The glucose tripled the B.O.D. load upon the plant and resulted in a breakdown in plant operation. Ruchhoft and Watkins[25] tentatively identified the predominant infesting organism in the diseased activated sludge at this plant as the filamentous organism *Sphaerotilus natans* and showed that the organism could be cultured upon a dextrose peptone phosphate agar. Pearse[26] reviewed the literature upon excessive carbohydrates in relation to sludge bulking. Agersborg and Hatfield[27]

found a rather poor activated sludge at Decatur and stated that the presence of 8 p.p.m. of dextrose probably encouraged the abundant growth of *Sphaerotilus natans* in the aeration tanks. Scott [28] observed great increases in the volume of activated sludge to which dextrose had been added. Scott showed that once the quantity of sludge had been increased, very long periods of aeration decreased the volume very little. Eldridge and Robinson [29] and Eldridge, Mallman and Robinson [30] reported that up to 400 p.p.m. of lactose were removed from solution by aeration with activated sludge in 6 to 8 hours. They noted an increase in pH of from 7.2 to 8.1 after carbohydrate feeding and suggested that the carbohydrate was completely oxidized in the above period. They obtained decreases in the quantities of suspended solids in their aeration tanks following lactose feeding and did not obtain any appreciable bulking until the sludge had been aerated three days without being fed. Infection of the sludge by *Sphaerotilus* was not mentioned by these observers.

Smit [31, 32] found that carbohydrates such as glucose, sucrose, lactose, and starch in quantities up to 1000 p.p.m. were all rapidly removed from sewage and that the prolonged addition of sewage containing carbohydrates in such quantities to activated sludge in time produced poor sludge infested with the filamentous organism *Sphaerotilus natans.* He concluded that the average sugar content of about 25 p.p.m. found in the strong Amsterdam sewage (8–18 gallons per capita) was far below the limit of harmfulness to activated sludge. Smit also stated that the products of glucose metabolism were not found, that contrary to his expectations, acids could not be traced, the pH changed very little and further experiments were needed to decide whether all of the sugar had been oxidized to carbon dioxide or other products had been formed. Schmiedt [33, 34] has denied the deleterious effect of carbohydrate on activated sludge and has reverted to the Willstätter theory of ferments adhering to the colloids to explain the oxidation phenomenon in activated sludge. He agrees, however, that wastes consisting mainly of carbohydrates are more difficult to treat than sewage containing colloidal albuminoid material.

From the above brief review it may be surmised that our knowledge regarding the removal of glucose from solution by activated sludge, the nature and relative quantities of dissimilation products formed from glucose by the reaction with activated sludge, and the effect of this reaction upon the sludge is fragmentary.

General Experimental Procedure

In these experiments three liters of the activated sludge mixed liquor chosen for study were transferred to a 4-liter pyrex serum bottle and the suspended sludge solids were allowed to settle for about thirty minutes. After settling, most of the supernatant liquor was siphoned off, a volume of solution containing from 2 to 3 grams of glucose was added and the volume was made up to three liters with distilled water.

A small portion, about 50 to 60 ml. of the initial activated sludge glucose mixture, was immediately removed from the aeration bottle for determination of the suspended solids, ash, pH and glucose content. The mixture was aerated continuously for definite periods after which samples were withdrawn for analysis.

Analytical Methods

The suspended solids and ash were determined according to Standard Methods.[35] The pH determinations in all experiments were made electrometrically employing a glass electrode.

An adaptation of the method recommended by Hassid [36, 37] for the determination of glucose in plant saps was used for the glucose determination. This method involves the reduction of potassium ferricyanide to ferrocyanide by the glucose in slightly alkaline media and the subsequent volumetric estimation of the ferrocyanide by oxidation with dilute standard ceric sulfate solution using Setopaline C as an internal indicator. The method is very simple and it is possible to make 90 to 100 glucose determinations in five hours with it.* Hassid states that the method has an accuracy compared with the Munson-Walker method of within 2–3 per cent. Our results with it indicate reproducibility within 3 per cent.

Preliminary tests indicated that our Cincinnati sewage and the supernatant liquor from the experimental activated sludge plant at the station contained only negligible quantities of materials capable of reducing ferricyanide (equivalent to 6.0 p.p.m. of glucose or less). Consequently, it was unnecessary to make blank glucose determinations upon sludge liquor or sewage to which glucose was to be added or to use and analyze an unfed sludge control.

Experimental Results

Typical results obtained in four experiments on glucose removal by activated sludge are tabulated in Table I and plotted in Fig. 1. These data confirm Smit's [31] results indicating that normal activated sludge sometimes removes glucose from solution very rapidly. In these experiments about 25 per cent of the glucose was removed in 30 minutes after which the percentage removal increased rapidly until glucose was depleted in 5 to 10 hours.

Pure culture zoogleal sludge removed glucose at a considerably lower rate than did normal activated sludge. The quantity of bacteria

* For this determination the sample of activated sludge liquor is withdrawn from the aeration bottle, filtered through No. 1 Whatman paper (further clarification is unnecessary) and a volume of filtered solution containing approximately 1 mg. of glucose is pipetted from a 2 ml. pipette (graduated in .1 ml.) into a 28 × 145 mm. test tube. Five ml. of alkaline ferricyanide are added and the tube is put into a wire basket which is placed in a 2 litter container of boiling water and heated for 15 to 17 minutes. Generally 8 to 13 tubes are heated at one time. Immediately following the heating period the tubes are cooled for 3 to 5 minutes in running water, acidified with 5 ml. of 5 N. H_2SO_4 and 7 drops of the 0.1 per cent aqueous Setopaline C indicator solution are added. The sample solutions are then rinsed from the tubes into 125 ml. Erlenmeyer flasks and titrated with approximately 0.01 N. standard ceric sulfate from a 5 ml. microburette. The ceric sulfate is standardized against a carefully prepared 1000 p.p.m. solution of glucose in distilled water.

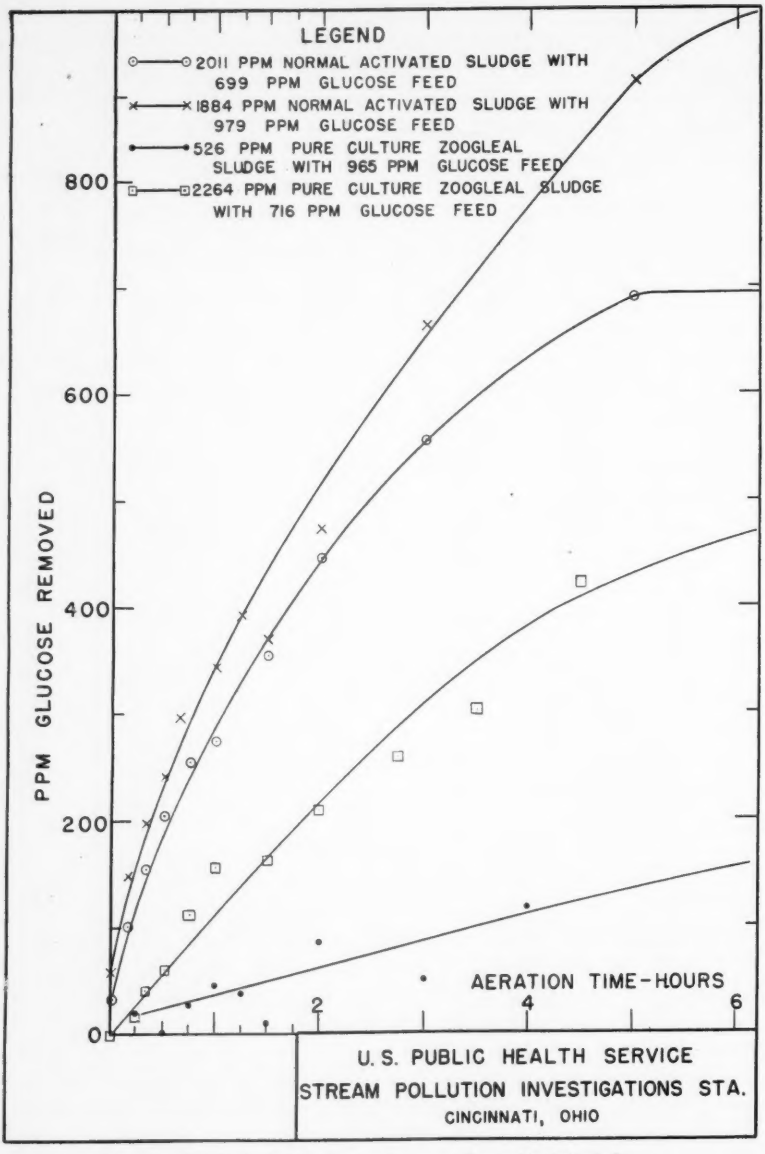

FIG. 1.—Typical glucose removal curves for activated sludges.

present very decidedly influenced the rate of glucose removal. With 526 p.p.m. of zoogleal bacteria (Exp. G–26) only 12.2 per cent of glucose was removed in 4 hours, while with 2264 p.p.m. of bacteria (Exp. G–42) 21.9 per cent was removed in one hour and 59.1 per cent in 4½ hours. On the basis of these removal performances it may be assumed that activated sludge contains organisms and enzymes more efficient in their glucose removal powers than these pure zoogleal cultures.

TABLE I.—*Typical Glucose Removal Results Obtained with Activated Sludges (at Room Temperature)*

	Normal Activated Sludge				Pure Culture Zoogleal Sludge No. 83			
Experiment No.	G 7		G 8		G 26		G 42	
Sludge Solids Volatile Solids Glucose Feed p.p.m.	2011 p.p.m. 1432 p.p.m. 699 p.p.m.		1884 p.p.m. 1328 p.p.m. 979 p.p.m.		526 p.p.m. 518 p.p.m. 965 p.p.m.		2264 p.p.m. 2124 p.p.m. 716 p.p.m.	
Time	Glucose Removed p.p.m.	Percentage Removed	Glucose Removed p.p.m.	Percentage Removed	Glucose Removed p.p.m.	Percentage Removed	Glucose Removed p.p.m.	Percentage Removed
Initial after mixing	33	4.72	59	6.03	—	0	0	0
10 min.	101	14.4	150	15.3				
15 min.					20	2.07	16.0	2.23
20 min.	155	22.2	199	20.3			42.0	5.87
30 min.	205	29.3	242	24.7	0	0	61.0	8.52
45 min.	255	36.5	297*	30.3	27	2.80	113.0	15.8
60 min.	275	39.3	344	35.1	45	4.66	157.0	21.9
75 min.			392	40.0	38	3.94		
90 min.	355	50.8	370	37.8	11	1.14	163.0	22.7
2 hrs.	446	63.8	474	48.4	86	8.91	210.0	29.3
3 hrs.	556	79.5	664	67.4	51	5.28	260.0†	36.3
3½ hrs.							304.0	42.5
4 hrs.					118	12.2		
4½ hrs.							423.0	59.1
5 hrs.	690	98.7	894	91.3				
23 hrs.	695	99.4	977	99.8	822	85.2	687.0	95.9

* 40 minutes.
† 2¾ hours.

A comparison of the glucose removal rate obtained with activated sludge, with sewage and with several of the biological agents common to sewage was made. These data are given in Table II and indicate that about 2000 p.p.m. of good activated sludge removes glucose at a much higher rate during the first three hour aeration period than any of the other agents tried. There is a lag of 5 hours before appreciable quantities of glucose are removed by Cincinnati domestic sewage. With cultures of *bacterium aerogenes* and *bacterium coli* containing about 21.6 and 32.6 million viable cells per ml. respectively, a lag of three hours was observed before appreciable quantities of glucose were removed. The much greater and earlier rate of glucose removal obtained with activated sludge gives evidence of the tremendous bacterial populations present in this sludge. It has been estimated [18] that activated sludge contains about 10,000 million bacteria per ml. The *Sphaerotilus natans* culture containing 422 p.p.m. of these organisms removed glucose at a considerably lower rate than the activated sludge.*

* When *Sphaerotilus natans* cultures are tested for glucose removal, the substrate must be properly balanced with nitrogenous and mineral constituents or glucose is removed very slowly. In this experiment glucose was fed with synthetic sewage under conditions in which maximum rates of removal are obtained.

TABLE II.—*Comparison of Various Biological Agents in Removing Glucose from Solution Under Aeration*
(At Room Temperature)

Aeration Time Hours	Glucose Removed p.p.m.					Percentage of Glucose Removed				
	Activated Sludge (1)	*Bacterium aerogenes* Culture (2)	*Bacterium coli* Culture (3)	Domestic Sewage	*Sphaerotilus natans* Culture (4)	Activated Sludge	*Bacterium aerogenes* Culture	*Bacterium coli* Culture	Domestic Sewage	*Sphaerotilus natans* Culture
½ hr....	172			0		17.2				
1 hr....	306	27	0	0		30.6	2.7	0		
3 hr....	660	46	13	0		66.0	4.6	1.3		
5 hr....	895	577	195	7	181	89.5	57.7	19.5	0.7	36.2
6½ hr...				350					35.0	
10½ hr...	Complete	660	424			100	66.0	42.4		
13 hr....				920					92.0	
24 hr....		704	771	Complete	480		70.4	77.1	100	96.0

(1) Activated sludge of 1940 p.p.m. suspended solids dosed with 1000 p.p.m. of glucose.

(2) A 48-hour 20° C. culture in standard nutrient broth was dosed with 1000 p.p.m. of glucose. Initial count in mixture was 21.6 million per ml.

(3) A 48-hour 20° C. culture in standard nutrient broth was dosed with 1000 p.p.m. of glucose. Initial count in mixture was 32.6 million per ml.

(4) A 24-hour culture in synthetic sewage containing 422 p.p.m. of organisms was dosed with synthetic sewage containing 500 p.p.m. of glucose.

It is interesting to compare the rate of glucose removal of these sludges and the removal of B.O.D. of sewages reported previously.[1] It may be assumed, for the purpose of this comparison, that the B.O.D. of glucose is removed at the same rate as its disappearance from solution. Using typical experiments, this comparison for normal activated sludge is as follows:

Exp. No.	Quantity of Sludge p.p.m.	Feed	L Value*	Percentage Reduction of L Value after Indicated Time in Hours				
				½	1½	3	5	10
7	2268	Settled Sewage	334	55.1	74.6	81.7	88.5	92.8
G7	2011	Glucose	745	29.2	50.9	79.5	98.7	99.+
5	2812	Synthetic Sewage	385	29.1	35.8	44.2	52.2	76.4

* Total Carbonaceous B.O.D.

This suggests that for the first two hours the rate of glucose removal by normal activated sludge is lower than the rate of removal of sewage organic matter which is largely suspended and colloidal material. Glucose, however, seems to be removed more completely in a shorter time than the nitrogenous organic matter (peptone and meat extract) in synthetic sewage.

A similar comparison of the B.O.D. removal obtained by pure culture zoogleal sludge follows:

Exp. No.	Quantity of Sludge p.p.m.	Feed	L value*	Percentage Reduction of L Value after Indicated Time in Hours			
				½	1½	3	5
9	2112	Settled Sewage	414	68.4	81.3	89.3	91.7
G42	2268	Glucose	764	8.52	22.9	39.8	63.8
2	1632	Synthetic Sewage	384	39.8	55.7	81.5	86.8

* Total Carbonaceous B.O.D.

This comparison indicates that the ability of the zoogleal culture to remove B.O.D. of sterile or synthetic sewage is very superior to its ability to remove glucose from solution.

Several experiments to determine the rate of glucose removal with increasing quantities of sludge have been completed. All of these have indicated that the rate of removal is directly related to the quantity of sludge under aeration. The data of a typical experiment are given

TABLE III.—*Glucose Removal with Increasing Quantities of Activated Sludge (At Room Temperature)*

Experiment G 17	A	B	C	D	E	F
Initial pH	7.2	7.2	7.2	7.2	7.2	7.2
Sludge Solids p.p.m.						
Initial	331	653	1253	1973	2621	3136
After 3 hours	308	716	1336	2052	2652	3188
After 5 hours	368	752	1384	2100	3008	3552
Glucose feed p.p.m.	515	515	515	515	515	515
Time	Glucose Removed p.p.m.					
Immediately after mixing	1.8	−6	−8	−5	25	48
15 min	3.2	15	42	27	54	64
30 min	46	43	29	51	80	82
60 min	23	21	60	75	103	142
2 hrs	47	60	105	157	201	256
3 hrs	52	78	141	216	284	356
5 hrs	67	117	223	306	415	485
24 hrs	199	365	Complete	Complete	Complete	Complete

in Table III and the results for glucose removal have been plotted in Fig. 2. The glucose removal results with the 3 lower sludge concentrations, A, B, C, show irregularities during the first hour. Thereafter, however, the glucose removal is quite regular with all concentra-

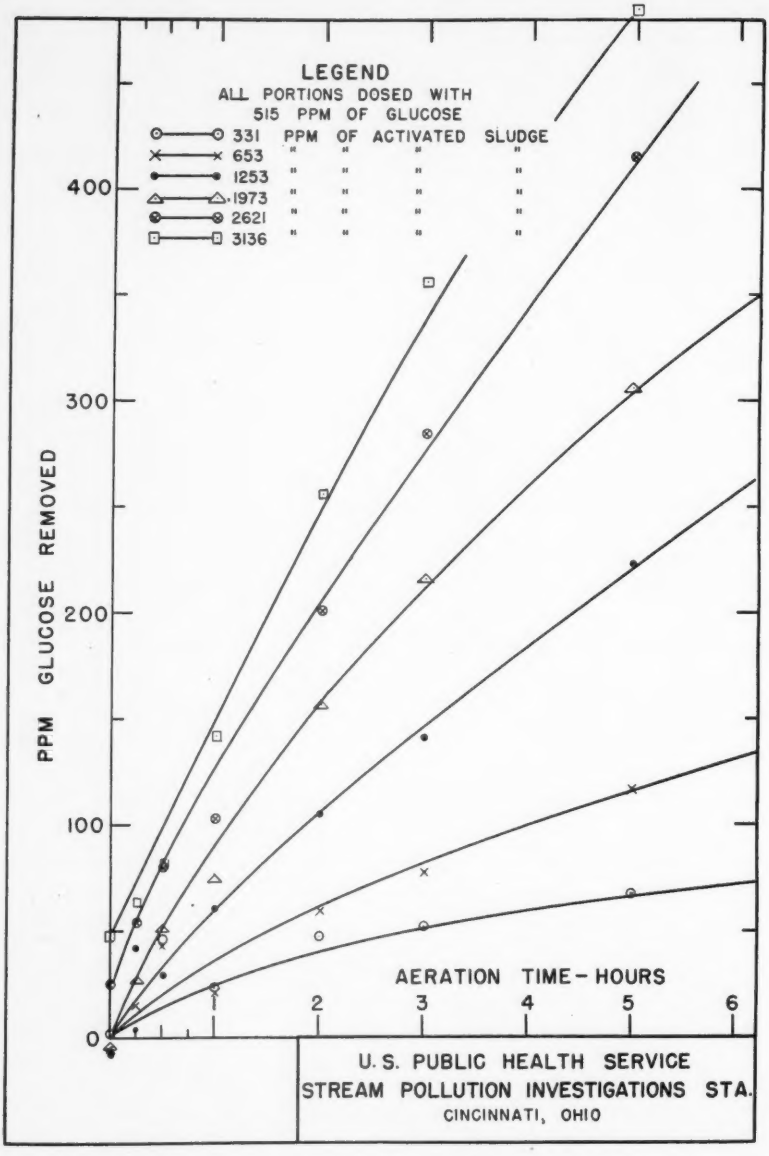

FIG. 2.—Glucose removal with increasing quantities of activated sludge.

tions of sludge. As Table III shows, the quantities of sludge solids present after 3 and 5 hours of aeration were definitely increased with the removal of glucose. The volatile matter content of these sludges also increased during the five hour aeration period. The mean volatile matter content of the sludges in this experiment was 50.95 per cent at

the start and this increased to 54.84 per cent after 3 hours and to 56.44 per cent after 5 hours.

The increasing rates of glucose removal for increasing quantities of sludge, after the first hour, suggests that the Freundlich adsorption law may apply. If this is true the removal data obtained after any time for all sludge concentrations should satisfy the expression:

$$\frac{X}{M} = a\,C^b$$

or

$$\text{Log}\,\frac{X}{M} = b\ \text{Log}\ C + \text{Log}\ a$$

where X = quantity of glucose removed,
M = quantity of sludge used,
C = concentration of glucose remaining in solution,
and a and b are constants.

The data obtained in the above experiment from the first to the fifth hour inclusive have been arranged in Table IV for plotting. In this

TABLE IV.—*Data of Experiment G 17 Arranged for Plotting to Determine the Application of the Freundlich Adsorption Expression*

$\frac{X}{M} = \frac{\text{p.p.m. of glucose removed}}{\text{p.p.m. of sludge solids}}$ C = p.p.m. of glucose remaining in solution.

Sludge Mixture	Initial Sludge Solids (M.) p.p.m.	Aeration Time—Hour at Which Observations were Made							
		1.		2.		3.		5.	
		$\frac{X}{M}$	C	$\frac{X}{M}$	C	$\frac{X}{M}$	C	$\frac{X}{M}$	C
A	325	.071	492	.145	468	.157	463	.191	448
B	650	.032	494	.092	455	.117	437	.167	398
C	1300	.046	455	.081	410	.106	374	.159	292
D	1950	.038	440	.081	358	.108	299	.146	209
E	2600	.040	412	.077	314	.107	231	.148	100
F	3250	.044	372	.079	258	.107	159	.138	30

computation the sludge solids results have been adjusted so that each higher concentration is an exact multiple of the lowest concentration. The initial suspended solids results were used with 1 and 2 hour glucose removal observations and the 3 and 5 hour suspended solids results were used with the removal observations at the corresponding times. These data have been plotted on a log-log scale, as shown in Fig. 3 with interesting results.

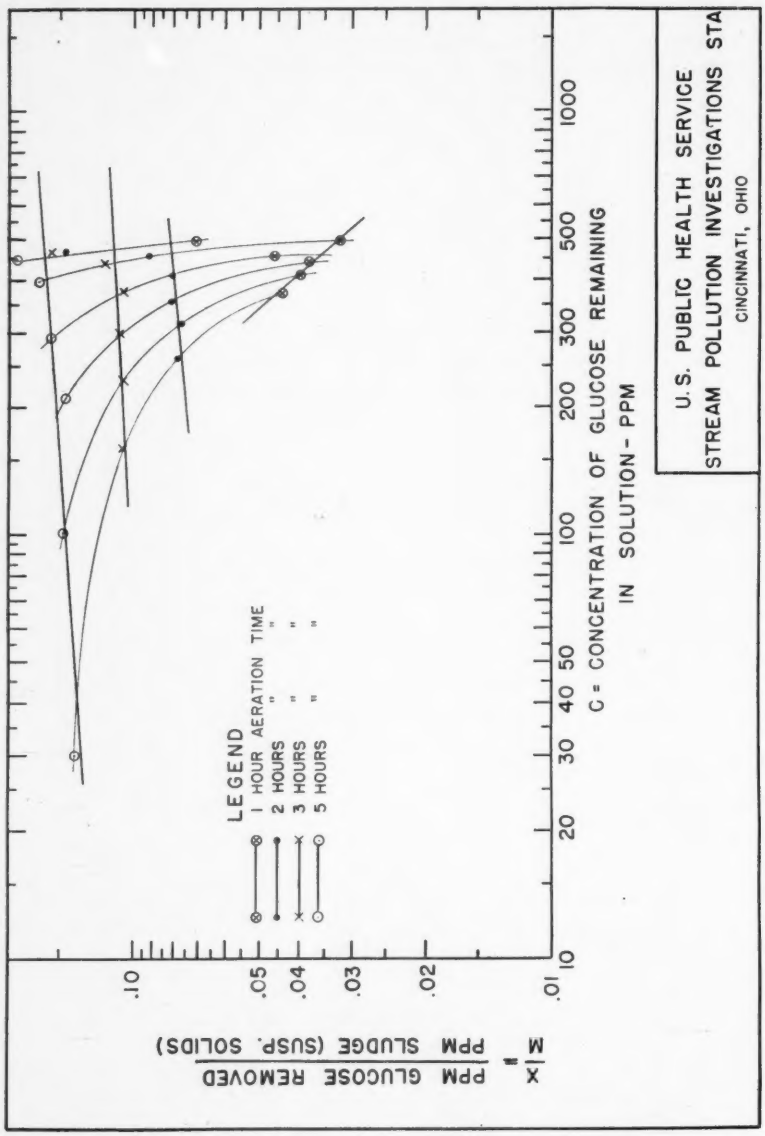

FIG. 3.—Relation between the ratio of glucose removed to the sludge solids and the concentration of glucose remaining in solution.

This figure shows that all points except those representing the lowest concentration of sludge fall within a reasonable distance of a straight line for the 2, 3 and 5 hour observations. A straight line may also be drawn through 4 of the 5 points for the one hour observation, neglecting the point for the lowest sludge concentration. Considering the relatively small quantities of glucose removed in one hour and the possibility of error in the glucose determinations, it is not surprising to find one of these observations with the lower sludge concentrations in disagreement. The observation points for each sludge concentration from the first to the fifth hour have been connected with a light curved line simply for convenience in following the movement of the point for a given sludge concentration with increasing aeration time. The straight line obtained at each observation time indicates that this reaction follows the expression $\log \frac{X}{M} = b \log C + \log a$. Consequently, it may be concluded that with normal activated sludge concentrations of 650 to 3250 p.p.m. and a glucose concentration of about 500 p.p.m. the Freundlich expression applies between the first and fifth hour. Agreement with this expression was not obtained when sludge concentrations below 650 p.p.m. were used.

The results of one experiment in which 478, 906 and 1088 p.p.m. of pure culture zoogleal sludge were tested for glucose removal ability were similar to the above results with normal activated sludge. These results are given in Table V. The removal obtained with all zoogleal

TABLE V.—*Glucose Removal with Increasing Quantities of Pure Culture Zoogleal Sludge*

Experiment G 16	D.	E.	F.
Sludge Solids p.p.m.	478	906	1088
Glucose Feed	631	631	631
Time	Glucose Removed p.p.m.		
Initial after Mixing	0	0	17
15 min.	22	54	84
30 min.	41	76	123
45 min.	24	63	109
60 min.	35	70	105
90 min.	9	55	91
2 hrs.	16	76	101
3 hrs.	21	120	115
5 hrs.	74	225	239
23½ hrs.	365	603	608

sludge concentrations were irregular during the first hour. Thereafter the removal results were fairly regular. Additional work with a larger number of concentrations of sludge is necessary to determine if glucose removal by pure culture sludge also follows the Freundlich expression.

Other Factors Affecting Glucose Removal by Activated Sludge

Temperature is one of the most important factors affecting glucose removal by activated sludge. In one experiment, to determine the effect of heat on the general removal mechanism, three portions of

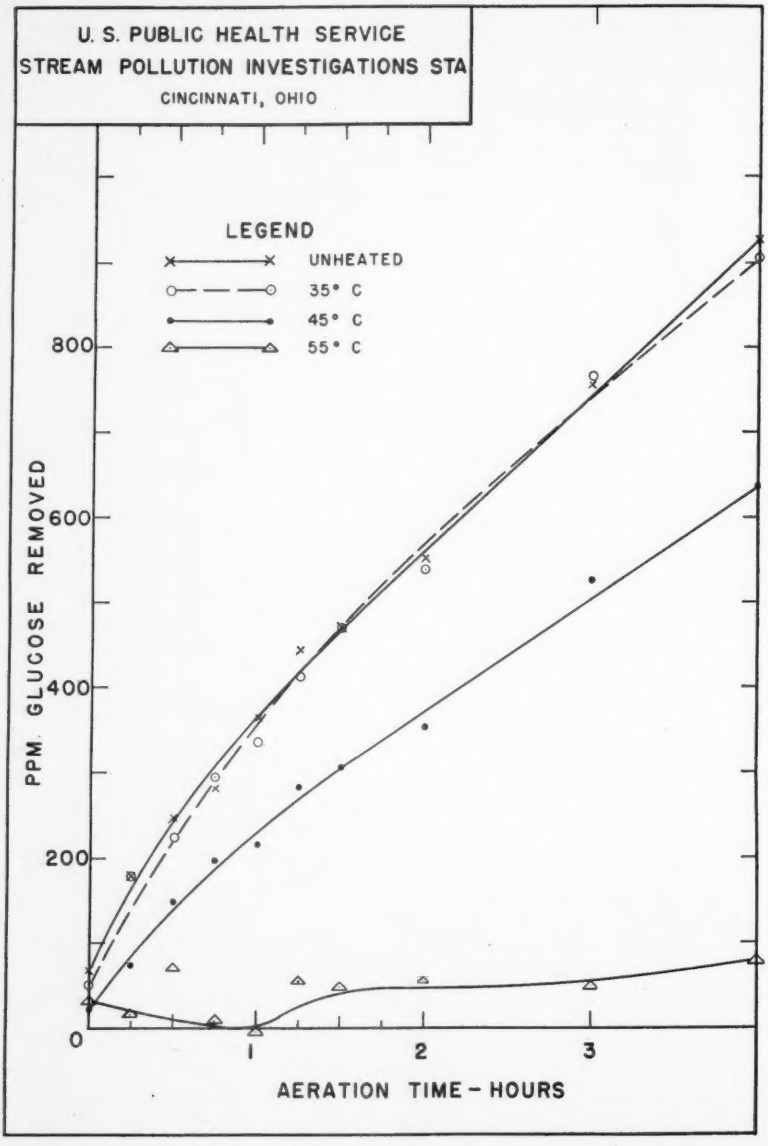

Fig. 4.—Effect of warming activated sludge for 10 minutes to various temperatures upon its glucose removal ability.

normal activated sludge were heated to 35°, 45° and 55° C. respectively, for ten minutes, and cooled to room temperature. Then 1000 p.p.m. of glucose were added to these three portions and to an untreated portion and all four portions were aerated at room temperature. The glucose removal results obtained are given in Table VI and plotted in Fig. 4.

TABLE VI.—*Effect of Warming Normal Activated Sludge to Various Temperatures for 10 minutes upon Its Glucose Removal Ability*

Sludge Solids 3200, Volatile Sludge Solids 1955; pH = 7.3, Glucose Feed 1000 p.p.m.

Sludge Portion Treatment	A Untreated	B 10 min. at 35° C.	C 10 min. at 45° C.	D 10 min. at 55° C.
Aeration Time	Glucose Removed p.p.m.			
Initial after Mixing.	67	53	22	34
15 min.	179	180	73	19
30 min.	247	225	149	71
45 min.	282	297	197	10
60 min.	367	338	216	−2
75 min.	446	414	282	56
90 min.	474	471	306	50
2 hrs.	552	540	354	58
3 hrs.	758	767	527	50
4 hrs.	928	907	638	82

This experiment showed that warming to 35° C. had no measurable effect upon the rate of glucose removal by activated sludge. Ten minutes at 45° C., however, had a very definite retarding effect upon the glucose removal rate and 10 minutes at 55° C. practically destroyed the ability of activated sludge to remove glucose during the first four hour aeration period. The glucose removal ability of this sludge was recovered, however, within the first 24 hour aeration period. This experiment suggests that the glucose removal rate by activated sludge depends upon an enzymic bacterial reaction which is very sensitive to temperatures over about 45° C. for even a very short time.

In two experiments the effect of aeration temperature upon glucose removal by normal activated sludge was studied. In the first test, aeration temperatures of 2 to 28° C. were used and in the second trial temperatures from 18 to 44° C. were maintained. In these experiments, portions of activated sludge which had been aerated at room temperature were heated or cooled to the desired temperatures. Each portion was dosed with 1000 p.p.m. of glucose solution at the temperature at which the sludge was to be aerated and aeration was started. The results obtained are given in Tables VII and VIII and are plotted in Figs 5 and 6. These figures show that the rate of glucose removal increased very decidedly as the aeration temperature was increased from 2.0° to 33–35.2° C. At the lower temperature only about 289 p.p.m. of glucose had been removed in 5½ hours, while at the higher temperature the entire 1000 p.p.m. had been removed in two hours. At

the highest aeration temperatures of these experimnts 41–44.3° C., the initial removal obtained immediately after mixing was greater than that obtained at any of the lower temperatures. The rate of removal after the initial mixing through the first hour was lower, however, than

TABLE VII.—*Effect of Aeration Temperatures upon Rate of Glucose Removal by Activated Sludge Temperatures 2.0° to 28° C.*

Sludge Solids 2672 p.p.m., Volatile Sludge Solids 1924 p.p.m., Glucose Feed 1000 p.p.m.

Sludge Portion	A	B	C	D
Aeration Temperature Range °C	2.0 to 8.2	10.0 to 13.0	19.3 to 19.6	27.0 to 28.0
Aeration Time	Glucose Removed p.p.m.			
Initial after Mixing	39	43	62	44
15 min.	71	58	126	154
30 min.	76	118	177	255
45 min.	103	168	250	344
60 min.	107	221	330	415
80 min.	138	255	370	482
100 min.	149	268	416	584
2 hrs.	173	313	480	663
3 hrs.	213	403	636	904
4 hrs.	228	499	783	Completely removed
5½ hrs.	289	591	988	

TABLE VIII.—*Effect of Aeration Temperatures upon Rate of Glucose Removal by Activated Sludge Temperatures 18.8 to 44.1° C.*

Sludge Solids 2824 p.p.m., Glucose Feed 1000 p.p.m.

Sludge Portion	A	B	C	D	E
Aeration Temperature Range °C	18.8 to 20.0	24.1	29.8 to 31.0	33.2 to 35.2	41.0 to 44.1
Aeration Time	Glucose Removed p.p.m.				
Initial after Mixing	66	61	118	157	199
15 min.	148	168	213	415	295
30 min.	204	257	448	505	356
45 min.	265	355	518	636	455
60 min.	360	454	604	741	509
80 min.	418	540	690	771	500
100 min.	500	647	842	835	506
2 hrs.	559	747	971	Complete removal	620
3 hrs.	697	Complete removal	Complete removal		606
4 hrs.	856				674
5½ hrs.	Complete removal				743

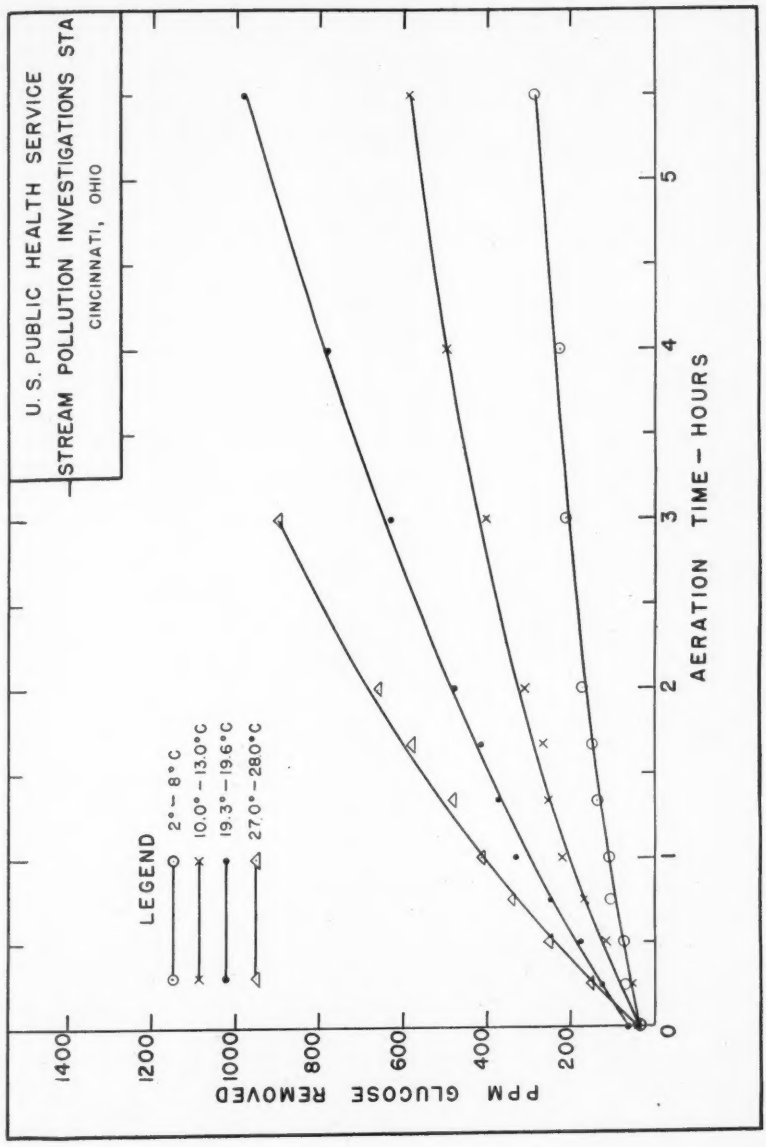

FIG. 5.—Effect of aeration temperatures upon the rate of glucose removal by activated sludge.

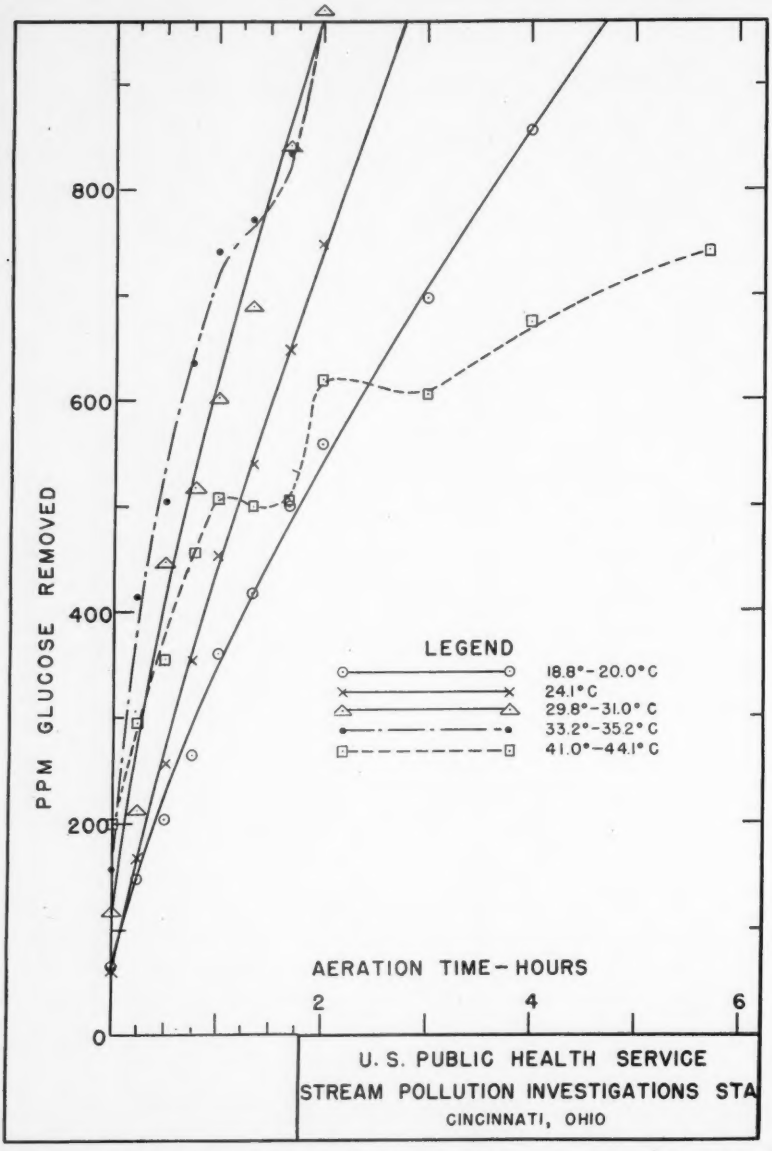

FIG. 6.—Effect of aeration temperatures upon the rate of glucose removal by activated sludge.

for the sludge portions aerated at about 30 and 35° C. After the first hour the removal rate fell considerably. Between the third and twenty-third hour (not tabulated) only 222 p.p.m. of glucose were removed. This indicates that an aeration temperature of 41–44.3° C. is very detrimental to the glucose removal mechanism of the sludge. In another experiment, activated sludge was conditioned by sewage feeding

and aeration at 42.6 to 43.0° C. for 44 hours before the glucose removal test was made. The conditioning at this temperature proved ineffective as the glucose removal capacity was completely destroyed thus indicating that this temperature is inimicable to the enzymic glucose removal mechanism of the sludge.

In another experiment, simultaneous tests were made upon a normal laboratory sludge of good quality developed at about 25° C. and a sludge from the station experimental plant that had been operated at aeration temperatures of about 1° to 10° C.* In this experiment samples of both sludges were divided into two portions, one portion of each sludge was brought to 27° C., dosed with a glucose solution at this temperature and aerated at the same temperature, while the second portion of each was brought to 1° C., dosed with glucose adjusted to this temperature, and aerated at the same temperature. The results of glucose removal obtained in this experiment, as given in Table IX, are

TABLE IX.—*Comparison of Glucose Removal Ability of Activated Sludge Developed at Winter and Summer Temperatures*

	Laboratory Sludge Temperature 27° C. Solids = 2170 p.p.m.		Experimental Plant Sludge Winter Temperature 1°–10° C. Solids = 3935 p.p.m.	
Aeration Temperature	27.4° C.	1.0° C.	27.4° C.	1.0° C.
Aeration Time	Glucose Removed p.p.m.			
Initial after Mixing	115	55	13	0
15 min.	203	128	11	5
30 min.	309	193	25	19
45 min.	341	200	72	25
60 min.	384	218	75	52
75 min.	434	243	119	36
90 min.	478	256	149	28
2 hrs.	414	200	108	0
3 hrs.	544	216	189	35
4 hrs.	689	226	260	40
5 hrs.	832	263	349	39
6 hrs.	936	270	404	70

instructive. This experiment shows that the glucose removal depends not only upon the aeration temperature during the period of glucose removal, but also upon the previous history of the sludge. The laboratory developed sludge removed glucose at the customary rate for 27° C. when aerated at 27° C. When this sludge was cooled and aerated at 1° C. its glucose removal rate fell, but this rate was considerably higher for the first 90 minute aeration period than the removal rate for the

* This temperature range is rather broad because this small plant is located in an unheated, glass covered building, without temperature control, subjected to winter temperatures. Consequently, the lower temperatures were obtaind during the night and early morning and the maximum temperatures were reached during sunshine in the afternoon.

winter temperature plant sludge aerated at 1° C. The plant sludge aerated at 1° C. removed glucose at a very low rate. At 27° C., however, this sludge did not reach the removal rate of the laboratory sludge aerated at 1° C. during the first 90 minute aeration period. This experiment suggests, therefore, that any preliminary treatment of a sludge which may affect its "quality" also affects the glucose removal rate that may be expected at any temperature.

A final experiment upon the temperature factor in glucose removal was carried out with samples of the same laboratory and plant sludge used previously, but after preliminary conditioning. The laboratory sludge was dosed regularly with sewage (twice a day) and aerated at winter temperatures, 1° to 10° C., for five days. The plant sludge was conditioned by similar dosing and aeration at 25 to 28° C. for three days. Each sludge was then divided into two portions and the previous experiment was repeated. The results obtained are given in Table X. The 5-day period of cold temperature conditioning had a remark-

TABLE X.—*Comparison of Glucose Removal Ability of Laboratory Sludge Conditioned at Winter Temperature and Winter (Plant) Sludge Conditioned at Summer Temperatures*

	Laboratory Sludge Conditioned at 1.0 to 10° C. Solids = 3010 p.p.m.		Experimental Plant Sludge Conditioned at about 27° C. Solids = 5170 p.p.m.	
Aeration Temperature	25° C.	4.0° C.	25° C.	4.0° C.*
Aeration Time	Glucose Removed p.p.m.			
Initial after Mixing	0	33	182	100
15 min.	72	75	272	176
30 min.	113	111	404	224
45 min.	143	129	580	274
60 min.	171	148	638	286
75 min.	187	159	688	256
90 min.	189	131	721	265
2 hrs.	194	139	790	323
3 hrs.	323	127	837	359
4 hrs.	515	183	894	450
5½ hrs.	654	288	Complete	458

* The aeration temperature in this portion slowly increased and reached 10° C. at the end of the five and one-half hour period.

able effect upon the glucose removal rates obtained from the laboratory sludge. This effect can be illustrated by comparing the rates of glucose removal in mg. per gram of sludge per liter for the first hour as follows:

Aeration Temperature °C.	Before Conditioning	After Conditioning at 1 to 10° C. for 5 Days
25 to 27° C.	177	57
1 to 4° C.	100	43

With winter plant activated sludge the following rates expressed similarly were obtained in these experiments:

Aeration Temperature	Before Conditioning	After Conditioning for 3 Days at 27° C.
25 to 27° C.	29	123
1 to 4° C.	20	55

The above comparison shows that the first hour glucose removal rates for laboratory sludge were reduced almost to the rate for winter plant sludge after five days of winter temperature conditioning. The winter plant sludge, on the other hand, had its first hour glucose removal raised from 20 per cent to 55 per cent at the low temperature and from 17 to 70 per cent at 27° C. of the laboratory sludge rates after three days conditioning at laboratory temperatures. These experiments indicate the very great influence of aeration temperature as a factor on the biological enzymic activity of the sludge.

Effect of pH

The effect of pH upon glucose removal rates was determined by subjecting the activated sludge to the desired pH for a short time and then readjusting the sludge to about 7.2, adding 1000 p.p.m. of glucose and completing the removal test as before. In one experiment four portions of sludge were taken, three of which were adjusted to pH 6.0, 5.1 and 2.8 $\pm$ 0.2 respectively, with N/10 phosphoric acid and allowed to stand for 20 minutes. Then all portions were readjusted to the neutral point with N/10 sodium hydroxide, the glucose was added and the test was run. The results are given in Table XI. Lowering of the

Table XI.—*Effect of Lowering the pH for 20 minutes upon Glucose Removal by Activated Sludge (At Room Temperature)*

Sludge Portion	A	B	C	D
pH to which Sludge was Subjected for 20 Minutes	7.2	6.0	5.2	2.8
pH at Start	7.2	7.2	7.2	7.0
Aeration Time	Glucose Removed p.p.m.			
Initial after Mixing	65	60	56	0
15 min.	126	151	139	2
30 min.	205	219	208	44
45 min.	275	263	265	23
60 min.	329	357	363	63
75 min.	380	366	393	39
90 min.	428	410	374	51
2 hrs.	510	490	471	95
3 hrs.	694	683	661	136
4 hrs.	836	817	796	183
23 hrs.	Complete	Complete	Complete	Complete

pH of the sludge to 5.1 for 20 minutes had practically no effect upon its glucose removal rate, while exposure to a pH of 2.8 for 20 minutes had a most destructive effect upon the glucose removal mechanism for the first 90 minutes. Thereafter this later sludge began to recover. In four hours it had not removed as much glucose as the other sludges had in 30 minutes. After 23 hours, however, this sludge had apparently recovered for the glucose removal was complete.

The effect of pH above the neutral point was determined in a similar experiment, the results of which are given in Table XII. In this ex-

TABLE XII.—*Effect of Raising the pH for 30 Minutes upon Glucose Removal by Activated Sludge (At Room Temperature)*

Sludge Portion	A	B	C	D
pH to Which Sludge was Subjected for 30 Minutes	7.2	8.1	9.2	11.0
pH at Start	7.2	7.1	7.1	7.1
Aeration Time	Glucose Removed p.p.m.			
Initial after Mixing	—	—	—	—
15 min.	51	79	73	18
30 min.	134	152	149	79
45 min.	181	163	212	127
60 min.	237	221	282	200
75 min.	214	232	309	196
90 min.	254	270	308	233
2 hrs.	323	331	372	278
3 hrs.	434	463	474	366
4 hrs.	507	514	541	423
21½ hrs.	995	987	991	991

periment N/10 sodium hydroxide was used to make the desired pH adjustment and after 30 minutes the pH of each sludge was readjusted to 7.1 with phosphoric acid. The results indicate that holding the sludge at a pH of 8.1 to 9.2 for 30 minutes stimulated rather than hindered glucose removal by the sludge. When the sludge was subjected to a pH of 11.0 for this period, however, the glucose removal rate was reduced.

In two additional experiments the pH of a number of portions of two activated sludges was adjusted to desired points, glucose was added and the effect of aeration at various hydrogen ion concentrations upon glucose removal was determined. The results for points below neutral are given in Table XIII and for points above neutral in Table XIV. The data indicated very little difference in glucose removal rates for the first three hours in the pH range from 5.8 to 7.2. After the first three-hour period the sludge at a pH of 6.6 maintained the maximum removal rate, with the neutral sludge portion second and the sludge

TABLE XIII.—*The Effect of Aeration of Activated Sludge at pH Values Below Neutral upon Glucose Removal (At Room Temperature)*

Sludge Solids 1810 p.p.m.

Sludge Portion.....	A	B	C	D	E
pH at Which Sludge was Aerated.....	7.2	6.6	5.8	5.0*	3.9
Aeration Time	Glucose Removed p.p.m.				
30 min.....	106	92	111	74	77
60 min.....	126	140	154	122	65
90 min.....	118	155	177	105	48
2 hrs.....	246	231	226	173	126
3¼ hrs.....	308	340	298	192	98
4 hrs.....	369	404	328	116	45
5 hrs.....	405	441	382	116	0
9 hrs.....	733	806	626	167	28
22½ hrs.....	Complete	Complete	Complete	412	200

* pH 5.6 for first 90 minutes.

TABLE XIV.—*The Effect of Aeration of Activated Sludge at pH Values Above Neutral upon Glucose Removal (At Room Temperature)*

Sludge Solids 2320 p.p.m.

Sludge Portion.....	A	B	C	D
pH at Which Sludge was Aerated.....	7.0	8.1	9.6	11.5+
Aeration Time	Glucose Removed p.p.m.			
30 min.....	3	31	63	69
60 min.....	123	117	66	134
90 min.....	171	168	133	152
2 hrs.....	231	188	185	177
3½ hrs.....	386	371	333	326
4¼ hrs.....	433	408	362	311
5 hrs.....	545	530	497	469
8 hrs.....	831	808	804	715
22½ hrs.....	Complete	Complete	Complete	Complete

at pH 5.8 next. There was not much difference, however, in the rate obtained at any of the above pH values even after 3 hours. Portion D was aerated at pH 5.6 for 1½ hours and then readjusted to pH 5.0 and the aeration was continued. The data indicated that there was a very decided reduction in glucose removal rates as the pH is decreased from 5.8 to 5.0 or lower. While 63 per cent of the glucose had been removed in 9 hours at pH 5.8 only about 17 per cent was removed at pH 5.0 during this time. At a pH of 3.9 there was apparently some glucose removal (about 126 p.p.m.) during the first two hours, but

thereafter the glucose was apparently returned to solution. After 9 hours of aeration more than 97 per cent of the glucose remained in solution and after 22½ hours about 80 per cent still remained in solution. It must be concluded that at a pH of 5.0 the glucose removal mechanism of activated sludge is greatly impaired and at 3.9 it is practically destroyed.

The data in Table XIV for pH values above 7.0 are not as conclusive as the low pH data. The glucose removal at pH values of 7.0, 8.1, 9.6 and 11.5 + are remarkably similar for the first two-hour period. Beyond this aeration time there seems to be some slight reduction in the glucose removal values as the pH was increased. At the end of 8 hours the percentage of glucose removal was 83.1, 80.8, 80.4 and 71.5 at pH 7.0, 8.1, 9.6 and 11.5 respectively. As it seems reasonable to suppose that auto-catalytic oxidation of glucose took place at the higher pH values, it is impossible to estimate without further investigation the extent of the damage to the common glucose removal mechanism of the sludge at these high pH values.

Glucose Removal Rates in Absence of Oxygen

The rate of glucose removal during intimate mixing of activated sludge and glucose substrate in the absence of dissolved oxygen was studied in several experiments. In one test, four equal portions of activated sludge were each given 1000 p.p.m. of glucose using different methods of keeping the sludge particles and glucose substrate in intimate contact. One portion (A) was aerated in the ordinary way using about 4 to 5 cu. ft. of air per hour for 3 liters of aeration mixture. This method kept the mixture aerobic at all times and also intimately mixes the sludge particles with the substrate. The second portion (B) was stirred with a paddle sufficiently to keep the sludge particles in complete suspension and about as intimately mixed as the particles in (A). Although a layer of oil was placed on the surface of the liquor, this layer tended to gather in the center of the rotating liquid surface so that there undoubtedly was some surface aeration in this portion. However, the surface aeration obtained in this way was very limited and was insufficient in view of the high oxygen demand of the sludge mixture to maintain aerobic conditions throughout the liquid. Portion (C) was agitated with nitrogen gas using about 4 to 5 cu. ft. per hour for a 3 liter volume of sludge mixture in the same way that air was used in portion (A). The sludge particles were as intimately mixed with the substrate as in portion (A), but in this case there was no opportunity for reaeration and the sludge liquor became devoid of oxygen within a few minutes after the start of the experiment. Portion (D), which was rotated continuously end over end in a number of completely filled glass stoppered bottles, also became devoid of oxygen within a few minutes after the start, but the sludge particles may not have been kept in such intimate contact with the glucose substrate because of the slow rotation employed (1 r.p.m.). The results given in

TABLE XV.—*Comparison of Glucose Removal by Activated Sludge Using Various Methods for Keeping the Sludge Particles and Substrate in Intimate Contact*

Sludge Portion.....	A	B	C	D
Means of Keeping Sludge and Substrate in Contact.....	Aeration with Air	Stirring with Paddle*	Agitation with Nitrogen Gas†	By Mechanical Rotation of Completely Filled Bottle‡
Aeration Time				
Initial.....	48	82	68	24
After Mixing				
15 min.....	300	179	121	87
30 min.....	439	221	150	134
45 min.....	552	303	211	239
60 min.....	635	336	283	314
90 min.....	868	374	355	392
2 hrs.....	Complete	466	418	426
3 hrs.....		557	380	461
4 hrs.....		601	469	—
4¾ hrs.....		614	—	
22½ hrs.....		859	657	640

* The surface of this portion was covered with an oil film. Each sample was removed by siphoning to prevent reaeration during sampling.

† Nitrogen gas at the same rate as air in (A) was bubbled through an aerator ball.

‡ One liter bottles completely filled were turned over endwise continuously once each minute. A.B.C. were held at room temperature of about 24° C. while D was held at 20° C.

Table XV show a very decided difference in the rate of glucose removal obtained with aeration and with other means of agitation in the absence of oxygen. In portion (A), with dissolved oxygen maintained by aeration, all of the glucose was removed from solution in two hours. Without oxygen the rate of glucose removal was reduced within 15 minutes. After about 2 hours the rate of removal was further reduced to such an extent that about 141, 343, and 360 p.p.m. of glucose remained in solution after 22½ hours of agitation in portion (B), (C) and (D) respectively. It is also interesting to note that in portions (C) and (D), in which all possibility of obtaining dissolved oxygen by reaeration during the agitation was removed, the lowest rates of glucose removal were obtained; while in portion B, where some slight reoxygenation was possible, slightly higher rates of glucose removal were obtained. A repetition of this experiment produced similar results. After 24 hours of mixing one of the portions agitated without oxygen still contained 254 p.p.m. of glucose. This portion was agitated for an additional hour without any further loss of glucose. It was then aerated for one hour and 64 p.pm. of glucose were removed. These experiments suggest that the organisms in the activated sludge process, which are responsible for the glucose removal and dissimilation, behave as obligate aerobes. From this it may be inferred that

the hydrogen activation in the glucose molecule in this reaction is such that only oxygen will act as an hydrogen acceptor. Or, if the theory holds that the oxygen is also activated, the predominate organisms in activated sludge require and activate oxygen for the completion of this reaction. In any case, the velocity of the glucose removal reaction under aeration and the reduction in velocity of the reaction in the absence of air indicates the importance of oxygen to the predominate organisms in this process and confirms both Smit [31] and Heukelekian's [22] glucose removal data.

Effect of Prolonged Reaeration

The effect of prolonged reaeration, without feeding, of activated sludge upon glucose removal was investigated, the results of which are given in Table XVI. These data indicate that prolonged reaera-

Table XVI.—*Effect of Reaeration upon the Glucose Removal Ability of Activated Sludge*

Reaeration Period Without Feed-hours.	18	42	162	306
Sludge Solids at Start of Glucose Removal Test.....	2036	2054	—	1832
Glucose Feed p.p.m....	750	750	750	750
Aeration Time Glucose Removal Test	Glucose Removed p.p.m.			
30 min.....	58	33	21	22
60 min.....	80	46	13	11
90 min.....	—	55	22	22
2 hrs.....	95	12	39	23
3 hrs.....		47	93	30
3½ hrs.....	198	—		—
4 hrs.....			105	63
4½ hrs.....		114		
5 hrs.....	297		132	87
6 hrs.....			—	78
6½ hrs.....		283	211	

tion, which is in effect starvation, steadily reduced the ability of the sludge to remove glucose at a rapid rate. The sludge of this experiment after 18 hours of reaeration removed 40 per cent of the glucose feed in five hours; but after about 13 days of reaeration it removed only about 11 per cent of the same glucose dose in the same time.

Supplemental Feeding

Two experiments were carried out to determine the effect of feeding other materials with glucose, upon the glucose removal rate by activated sludge. The results obtained are presented in Table XVII.

TABLE XVII.—*Effect of Supplemental Feeding upon Glucose Removal by Activated Sludge*

Experiment	G 13		G 14	
Portion	Control	Supplemental Feed	Control	Supplemental Feed
Glucose Feed p.p.m.	440	470	445	475
Supplemental Feed	0	Domestic Sewage	0	Peptone Solution (750 p.p.m.)
Aeration Time	Glucose Removed p.p.m.			
Initial after Mixing	51	110	—	—
10 min.	56	114	78	107
20 min.	57	115	95	137
30 min.	82	132	104	99
40 min.	91	141	114	137
50 min.	95	144	103	133
60 min.	116	166	153	173
75 min.	123	189	159	188
90 min.	138	206	168	173
2 hrs.	166	253	202	232
3 hrs.	208	333	241	256
5 hrs.	352	430	348	365
23 hrs.	Complete	Complete	Complete	Complete

The first experiment indicates that the feeding of sewage with glucose increases slightly the rate of glucose removal by activated sludge. The results obtained when peptone was used as a supplemental feed were not as definite as the results with sewage, but this experiment seems to indicate that peptone certainly does not reduce the glucose removal rate and may increase it very slightly.

Effect of Repeated Glucose Feeding

After determining the glucose removal rate on a sample of activated sludge, two 8-liter portions of this sludge were treated as follows: One portion was dosed with domestic sewage daily for 9 days and then the glucose removal test was repeated. The second portion was dosed daily with the same sewage as the above portion, but fortified with 500 p.p.m. of glucose. This was continued for seven days and the glucose removal test was repeated. The results obtained in this experiment are presented in Table XVIII. The glucose removal rate for this sludge was improved slightly after dosing it daily for 9 days with sewage. After one week of daily treatment with sewage plus 500 p.p.m. of glucose, however, the glucose removal rate was so accelerated that the time for complete removal of the glucose was reduced from about 3 hours to 30 minutes. The increase in the suspended solids obtained with glucose fortified sewage in this experiment is quite remarkable. During nine days of sewage feeding, the quantity

TABLE XVIII.—*Effect of Repeated Glucose Feeding upon Glucose Removal by Activated Sludge (Using 500 p.p.m. of Glucose per Day)*

Sludge Portion	A	B	C
Description	Control (Initial Sludge)	Same as A Except that it was Dosed Daily with Sewage for 9 Days	Same as B Except that it was Dosed Daily with Same Sewage Fortified with 500 p.p.m. of Glucose for 7 Days
Sludge Solids Change during Treatment p.p.m.			
From	—	2640	2640
To	—	3260	5340
Sludge Solids Used in Glucose Removal Test			
Total Suspended p.p.m.	2640	2608	2196
Volatile Suspended p.p.m.	1684	1608	1724
Aeration Time	Glucose Removed p.p.m.		
Initial after Mixing	47	100	206
10 min.	99	168	414
20 min.	147	221	462
30 min.	175	261	Complete
45 min.	209	316	
60 min.	228	360	
75 min.	265	387	
90 min.	295	436	
2 hrs.	356	448	
3 hrs.	458	Complete	

of sludge under aeration in the portion fed with sewage only increased by 620 p.p.m. If the proportionate increase of solids due to sewage for seven days is deducted from the total solids increase in the glucose fortified sewage fed sludge (C), an increase of 2220 p.p.m. of sludge due to glucose feeding is obtained. As 3500 p.p.m. of glucose was fed during this interval, the sludge increase due to glucose represents 63 per cent of the glucose weight recovered as sludge.

In another experiment, 2000 p.p.m. of glucose were fed to activated sludge daily for three days and the rate of glucose removal was followed each day. The results obtained are given in Table XIX and indicate that in this experiment the sludge was overloaded with respect to glucose. The rate of glucose removal fell upon the second and third feeding. While 86 per cent of the glucose was removed in 23 hours in the first day, only 46 per cent was removed on the third day in the same time. In this case, additional nitrogenous material in the form of sewage or peptone was not given with the glucose. It is probable that a better performance of the sludge with this quantity of glucose would have been obtained had this been done.

TABLE XIX.—*Effect of Feeding 2000 p.p.m. of Glucose Daily upon Glucose Removal by Activated Sludge*

	First Day	Second Day	Third Day
Aeration Time	Suspended Solids p.p.m.		
Initial	2376	3344	4135
1 hr.	2744	3451	4063
3 hrs.	2608	3512	—
5 hrs.	2764	3570	—
23 hrs.	3480	4145	4477
	Glucose Removal p.p.m.		
Initial	0	—	0
15 min.	44	28	0
30 min.	79	74	0
45 min.	99	91	0
60 min.	111	117	41
90 min.	205	113	61
2¼ hrs.	297	120	88
3 hrs.	340	205	111
4 hrs.	497	284	135
5 hrs.	618	373	138
23 hrs.	1720	1176	928

EFFECT OF CHLORINATION

As chlorination is often recommended as a method of controlling or curing the activated sludge process when difficulties are encountered, one experiment to determine the effect of chlorination upon the glucose removal reaction was completed. In this experiment, the desired doses of chlorine, as H.T.H solution, were added and after 15 minutes of contact any residual chlorine was neutralized with sodium sulfite solution. The glucose solution was then added and the glucose removal tests completed in the ordinary way. The data for this experiment are presented in Table XX. It will be seen at once that the 15 minute contact period with 16 p.p.m. of chlorine in portion D practically destroyed the glucose removal mechanism and prevented the removal of glucose for four hours. Between the fourth and twenty-first hour of aeration, however, the sludge regained its power to remove glucose. A 6.2 p.p.m. dose of chlorine for 15 minutes also injured the glucose removal mechanism. With this dose only about 109 p.pm. or 15.6 per cent of the glucose had been removed after 4 hours of aeration. When the values for glucose removal for portions A and B of Table XX are calculated in terms of p.pm. of glucose removed per gram of sludge, it is found that 1.6 p.p.m. of chlorine effected the glucose removal very slightly. This experiment indicates that the quantity of chlorine that has been suggested by Smith and Purdy [38] to correct sludge bulking caused by fungus growths is not great enough to interfere seriously with the ordinary enzymic reactions such as are indicated by the

glucose removal mechanism. However, chlorination of activated sludge is attended by the serious danger of over-chlorinating. This would destroy not only the plankton growths as pointed out by the above authors, but it would destroy the normal bacterial reactions of the sludge as shown in portion (D) in the above experiment.

TABLE XX.—*Effect of Chlorination upon Glucose Removal by Activated Sludge*

Sludge Portion	A	B	C	D
Amount of Cl. p.p.m. Given for 15 Minutes and then Neutralized	0	1.6	6.2	16.0
Sludge Solids p.p.m.	1684	1480	1412	1376
Glucose Dose p.p.m.	700	700	700	700
Aeration Time	Glucose Removed p.p.m.			
Initial after Mixing	48	66	8	5
15 min	91	98	23	19
30 min	152	142	32	0
45 min	182	158	44	0
60 min	238	192	38	0
75 min	270	183	65	0
90 min	321	247	31	0
2 hrs	380	284	80	0
3 hrs	513	404	147	41
4 hrs	613	493	109	0
21 hrs	Complete	605	606	606

SUMMARY AND CONCLUSIONS

The rates of removal of glucose from substrates by activated sludge have been investigated. Experimental data are presented to illustrate the rates of removal of glucose from substrates by normal activated sludge and by pure cultures of certain bacterial species found in activated sludge or domestic sewage. The effect of various factors such as temperature, pH, dissolved oxygen, supplemental feeding and acclimatization on these removal rates has been determined. It has been shown that glucose is removed from solution much more rapidly by activated sludge than by domestic sewage, pure cultures of *Bact. coli, Bact. aerogenes, Sphaerotilus natans,* or zoogleal sludge. The rate of glucose removal by activated sludge is a function of the quantity of sludge present and, after the first hour, the removal rate follows the Freundlich absorption equation. A comparison of the rates of removal by activated sludge of glucose and of settled or synthetic sewage indicated that glucose is removed more slowly than the carbonaceous organic matter of settled sewage and more rapidly than the nitrogenous material of synthetic sewage. The zoogleal sludge, however, removed synthetic sewage at a higher rate than glucose.

Temperature studies showed that heating the sludge for 10 minutes at 35° C. did not affect the removal rate, 10 minutes at 45° C. reduced the rate for a considerable time and 10 minutes at 55° C. practically destroyed the glucose removing mechanism of the sludge. The glucose removal rate roughly doubled for each 10° C. increase in aeration temperature from 0 to 35° C. Aeration temperatures over 45° C. were inimicable to glucose removal by activated sludge. Aeration temperatures of the sludge previous to the addition of glucose also affected the glucose removal rate. Winter sludge dosed with glucose and aerated at 27° C. did not remove glucose at as rapid a rate as the summer sludge at this temperature. Summer sludge, to which glucose was added and then aerated at 1.0° C., removed glucose at higher rates than winter sludge so treated. Acclimatization of the sludges at either temperature tended to bring the glucose removal rate to normal for the aeration temperature employed.

Lowering the pH of the sludge for 20 minutes to 5.2 before the addition of glucose, definitely retarded glucose removal slightly, and lowering to pH 2.8 for the same time practically destroyed the glucose removing mechanism for several hours. Subjection of the sludge to a pH up to 11.0 for 30 minutes followed by neutralization had very little effect upon the glucose removal reaction. When activated sludge was aerated below a pH of about 6.0 the rate of glucose removal was reduced and at a pH of 3.9 it was practically stopped. The experiments above pH 7.0 were not conclusive but apparently there was little if any reduction in the glucose removal rate when sludge was aerated at pH values up to 9.6.

The results show definitely that aeration was required to maintain the glucose removal rate. In samples in which the activated sludge was maintained in contact with the glucose substrate by stirring with a paddle, by agitation with nitrogen or by mechanical rotation of a completely filled bottle, the glucose removal rate was very much reduced within a few minutes. The experiments indicate, however, that while oxygen was needed the ratio of oxygen used to glucose removed was low.

When glucose was added to sewage or peptone and fed to sludge, these nitrogenous materials did not retard the glucose removal rate and possibly increased it slightly. When glucose alone was fed in large doses, the glucose removal mechanism of the sludge failed after several treatments. This indicated the deficiency of certain nutritive elements, probably nitrogen and phosphorus, for the continued maintenance of the process. When sewage containing glucose was fed regularly to activated sludge for a period of about a week, the rate of glucose removal was very much accelerated. Sludge acclimated in this way can remove 1000 p.p.m. of glucose from solution in about 90 minutes. This acclimatization phenomenon may be explained upon the basis of a multiplication of certain special glucose removing microorganisms in the sludge or by the development of adaptive glucose enzymes of the predominant bacteria of the sludge.

Starvation of the sludge by reaeration without additions of food steadily reduced the glucose removal rate. The effect of chlorination on activated sludge depended entirely upon the chlorine dose used. When a mixed liquor containing about 1500 p.p.m. of suspended sludge solids was dosed with 1.6 p.p.m. of chlorine, the glucose removal reaction was only slightly affected. When the chlorine dose was increased to 6.2 p.p.m., a 75 per cent reduction in the glucose removal rate was obtained and with 15.0 p.p.m. of chlorine, the glucose removal reaction was completely stopped for four hours.

The results of this study, using glucose as a representative of the large fraction of organic material present in true solution in sewage, indicate the probability of the very rapid removal of such constituents from sewage by the purely biochemical processes in activated sludge and demonstrate the sensitivity of such processes to temperature, proper pH, balanced nutrients, starvation, chlorination, acclimatization and to oxygen depletion. Under the maintenance of proper conditions, such constituents can be removed at rates which compare favorably with the removal of material in suspension from sewage by activated sludge. The metabolism of the glucose removed from solution by the sludge will be considered in a following paper. Acknowledgment is made of the cooperation of Principal Bacteriologist C. T. Butterfield and Assistant Bacteriologist Elsie Wattie in preparing the pure cultures of zoogleal sludges and to Cytologist James B. Lackey for the cultures of *Sphaerotilus natans* used in these studies.

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Plant Operation

PROPERTIES OF SLUDGE WHICH AFFECT ITS DISCHARGE THROUGH 24-INCH PIPE

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In an exceptionally interesting article on the viscosity of pseudo-plastic properties of sewage sludges, Hatfield [1] has called attention to the relation of solids concentration and viscosity and the effect of temperature on the "apparent viscosity." He indicates that these two factors may cause considerable friction losses and difficulties in sludge pumping. Merkel [2] studying the flow properties of digested sludges in 20 cm. pipes shows head losses for various sludge concentrations. A committee report of the American Society of Civil Engineers by Pearse, Holmes and Keefer [3] concluded, on the basis of experiments with sludges flowing in 6 to 12 in. pipes, that sludge friction losses increase with a decreased moisture content and that friction losses tend to increase with lower temperature.

The experiments and calculations given by Pearse, *et al,* and Merkel dealt with sludge movement in pipes up to 12 in. in diameter of comparative short lengths. The question arises whether the same factors would be of importance in a pipe line of larger diameter and if so, to the same extent; and whether a rather long pipe of larger diameter accelerates the effects. Answers to these questions are of considerable practical importance in some instances and perhaps of theoretical interest as well.

Operation

The sludge produced at the Elizabeth Valley Joint Meeting sewage treatment works, which serves eleven municipalities, is barged to sea. Sludge collected in the settling tank sumps is conveyed through an 8 in. cast iron suction line to plunger type pumps, thence through a venturi meter to a sludge thickener tank and thence to storage tanks, or may be pumped direct to the storage tanks. The cost of disposal of the sludge is directly related to the volume of sludge produced and barged. Natural concentration of fresh solids in the storage tanks with certain control measures results in production of a dense sludge. Under certain conditions the thickening process is so great that the facilities for sludge removal may be overtaxed. The sludge thickener tank is used as a receiving tank for fresh solids, where the scum from the settling tanks is mixed with the solids and dewatered as necessary.

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Dept. Water and Sewage Research.

The storage tanks are provided with six valves at different elevations to allow for withdrawal of the separated water. This operation results in from 25 to 40 per cent reduction in volume.

The amount of sludge handled daily from the settling tanks averaged, during 1937, about 74,000 gal. with an average concentration of 5.4 per cent solids. The amount of sludge handled daily during 1938 averaged about 72,600 gallons. After storage the sludge barged during 1937 averaged 8.0 per cent solids with an average ash content of 23 per cent, resulting in a volume reduction of from 30 to 35 per cent. The reduction in volume affected during 1938 by controlled decantation was 41.5 per cent of the fresh sludge. The storage tanks have a capacity of 1,252,000 gal. or 5,460 tons of sludge.

Loading of the sludge into barges for disposal at sea is accomplished whenever necessary by means of centrifugal pumps through a 24 in. pipe line 4,400 ft. long. The time required for loading about 3,500 tons may vary from 4 to 12 hrs. depending upon the character, density and temperature of the sludge. Experience has shown that freshly collected sludge of any moisture content above 93 per cent can readily be handled in large volumes by suitable centrifugal pumps. When the sludge is stored separation of water occurs in layers. This stratification may occur at various levels depending upon atmospheric and other conditions. As much as possible of the separated water is decanted by means of the valves placed at various levels. Water which remains does not readily mix with the sludge during pumping. Upon standing the concentrated sludge acquires a jelly-like character, and does not flow readily by gravity into the pipes. Pumping such material results in difficulties from cavitation or water breaking through.

Sludge with a solids concentration of 8 per cent or higher cannot be efficiently pumped to the barges through the 24 in. pipe line unless properly agitated before reaching the pumps, such as by the re-introduction of water under pressure.

Experience has also shown that pumping is affected by changes in temperature of the sludge. At lower temperatures the time required for loading a given quantity of sludge appears to increase, and frequent interruption is necessary to shut down the pumps for blowing out the pipe lines to the barge with compressed air.

Experimental

After the first four barge loads had been discharged and necessary adjustments made an accurate record was kept of the time required to pump sludge. During pumping samples of sludge were taken every 15 mins., the temperature and changes in prevailing head were recorded and the sludge analyzed for total solids and ash. After about two years operation the results were tabulated, summarized and the data obtained studied for possible relationships of sludge concentration, ash content and temperature with changes in head and rates of loading.

Results

The average results obtained on solids concentration, ash, temperature and prevailing head are given in Table I, together with some pertinent notes. The solids concentration varied from 5.2 to 8.4 per cent, the temperature from 48 to 73.5° F., the ash content from 21.4 to 40.1 per cent of the dry solids, the average head from 14 to 42 ft. and the loading rate from 1,000 to 3,555 gal. per min. Attempts to pump higher average solids concentrations than 8.5 per cent failed with plant facilities then available. Experience and examination of the results obtained seemed to indicate that the temperature and the solids concentration played a role in decreasing the loading rate and in increasing the pumping head.

Solids.—Perusal of the data obtained led to an attempt to show the relation between solids concentration and the prevailing head. For this purpose the total solids ranging within narrow limits were averaged and plotted against the average head for these concentrations, ir-

Table I.—*Chronological Results on Barge Loadings*

Trip No.	Date	Sludge		Loading Time, Min.	Loading Rate, G.p.M.	Total Solids, %	Avg. Head, Ft.	Sludge Temp., °F.	Ash, %	Remarks
		Tons	Gal.							
5	7/ 9/37	3545	815,300	308	2640	6.00	14	70	—	
6	7/23/37	3500	805,000	308	2610	5.24	13	70	—	
7	8/ 4/37	3500	805,000	275	2925	6.18	16	70	25.9	
8	8/21/37	3490	803,000	241	3330	7.11	18	72	31.3	
9	9/ 8/37	3460	796,000	327	2435	7.57	18	70	29.4	
10	9/21/37	3520	810,000	334	2420	5.59	14	67	28.0	
11	10/ 7/37	3175	730,000	410	1780	5.92	14	67	23.4	Suction lines probably partly clogged
12	10/24/37	3535	813,000	245	3320	6.45	14	66	24.8	
13	11/14/37	3400	782,500	323	2420	7.39	20	64	25.9	
14	11/27/37	3510	807,500	416	1940	7.32	22	62	23.5	
15	12/14/37	2900	667,000	315	2120	6.72	26	58	30.0	Valves frozen—thawing cut short loading time
16	12/28/37	3370	775,000	440	1760	6.40	28	55	22.5	
17	1/15/38	3500	805,000	625	1290	6.80	30	54	22.4	
18	2/11/38	3425	765,000	510	1500	7.20	34	50	23.8	
19	3/ 4/38	3525	812,000	615	1320	6.57	34	48	21.4	
20	3/24/38	3500	805,000	503	1600	7.29	34	52	22.7	
21	4/10/38	3410	784,000	790	1000	7.91	34	55	22.1	
22	4/26/38	3090	711,000	466	1525	7.11	30	57	24.8	Stoppage-reg. 35 lb./sq. in. loading time lost 75 min.
23	5/ 7/38	2850	656,000	280	2340	7.23	28	61	28.9	Special loading made for observations at sea
24	5/27/38	3300	759,000	400	1895	7.32	28	62	23.4	First sludge containing ground up screenings
25	6/11/38	3500	805,000	405	1990	8.19	22	67	24.6	
26	6/26/38	3500	805,000	411	1960	8.41	18	69	24.2	Increased size suction and cleanout facilities used for 1st time

TABLE I.—*Continued*

Trip No.	Date	Sludge		Loading Time, Min.	Loading Rate, G.p.M.	Total Solids, %	Avg. Head, Ft.	Sludge Temp., °F.	Ash, %	Remarks
		Tons	Gal.							
27	7/ 9/38	3500	805,000	319	2520	8.07	16	70	30.2	
28	7/27/38	3450	794,000	267	2970	8.35	18	72	40.1	
29	8/13/38	3475	800,000	285	2805	8.07	18	73.5	36.6	
30	8/27/38	3260	750,000	315	2380	7.61	18	73.5	31.9	
31	9/17/38	3400	782,500	272	2875	6.76	16	72	26.0	
32	10/ 4/38	3200	736,000	295	2495	8.03	18	69	30.3	Loading time curtailed
33	10/20/38	3475	800,000	327	2445	8.20	20	69	24.8	Increased H.P. and speed of No. 1 pump effective this loading
34	11/ 8/38	3510	807,500	255	3165	7.36	18	67.5	23.7	
35	12/ 1/38	3475	800,000	225	3555	7.14	20	61	23.5	
36	12/20/38	3475	800,000	385	2075	7.66	28	58	23.6	
37	1/24/39	3400	782,500	390	2005	7.77	34	57	25.0	
38	1/24/39	3525	812,000	425	1910	7.45	38	55	21.4	
39	2/13/39	3350	771,000	358	2155	7.78	40	53	26.0	Difficulties noted from low temp. and viscosity therewith
40	3/ 2/39	3475	800,000	534	1500	7.93	42	52	23.6	Extra long time provided for loading due to previous difficulties
41	3/21/39	3525	812,000	475	1710	8.04	42	52	24.5	
42	4/ 4/39	3500	805,000	520	1550	7.94	40	53	24.2	
43	4/19/39	3275	753,000	633	1190	7.72	42	54	25.1	Peak air pressure used in clearing force main 31 lb./sq. in.
44	5/ 4/39	3450	794,000	540	1470	7.44	38	57	23.8	
45	5/22/39	3530	813,500	628	1300	7.82	40	61	24.1	Peak air pressure used in clearing force main —25 lb./sq. in.

respective of the temperature of the sludge (Fig. 1). The curve definitely shows a material increase in head with increased concentration of solids, although in general higher temperatures prevailed with lower solids concentration and lower head. The rate of loading seems to follow the general trend so that with increased solids concentration the prevailing head increases and the rate of loading decreases. This is indicated in Table II where the various averages are shown. Calculating the "viscosity" of the sludge in centipoises seems to show definitely a direct relationship with the loss of head and the solids concentration. This is shown in Fig. 2, where the average prevailing head and viscosity is plotted against the solids concentrations.

The average results shown in Fig. 1, may indicate that there is a proportionally direct relation between the sludge concentration and prevailing head. It is conceivable that the temperature effect is of sufficient importance to change the shape of the curve and for that reason a number of the results were selected with varying sludge concentrations and a fairly constant temperature. The results plotted in Fig. 3 show a curve more in accordance with the laboratory results

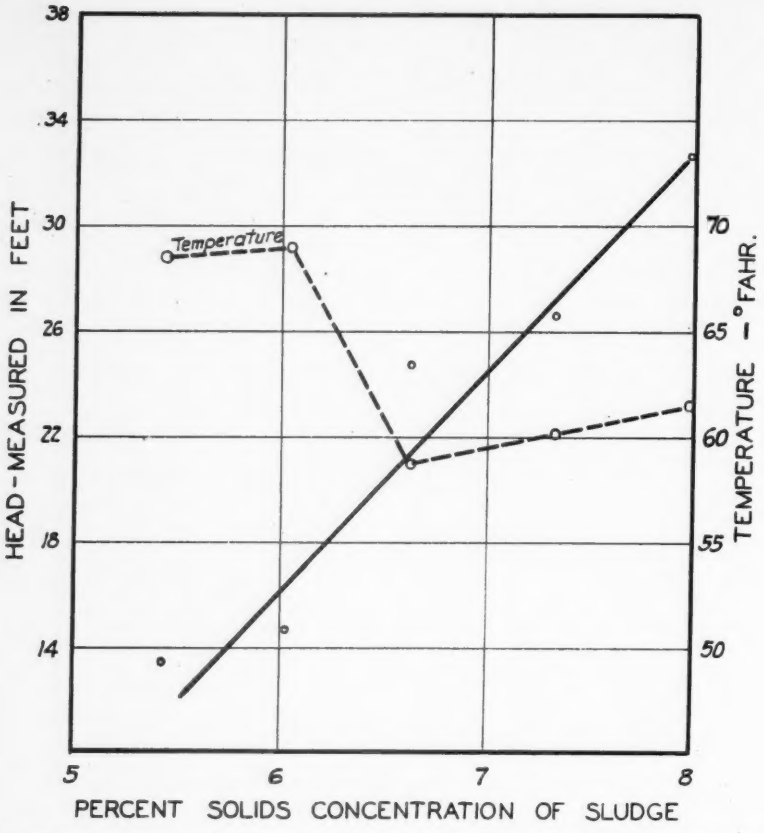

FIG. 1.—Effect of sludge concentration on prevailing head irrespective of temperature of sludge.

TABLE II.—*Relation Between Solids Concentration, Head and Rate of Loading*

Number of Bargings	Total Solids Range, %	Avg. Total Solids, %	Avg. Prevailing Head, Ft.	Avg. Temp., ° F.	Avg. Rate of Flow, G.p.M.	Calc. Viscosity, C.P.
2	5.2–5.6	5.43	13.5	68.5	2515	690
3	5.9–6.2	6.03	14.7	69.0	2672	680
6	6.4–6.8	6.62	24.7	58.8	2114	1450
13	7.1–7.6	7.33	26.6	60.1	1891	1750
16	7.7–8.4	7.98	32.6	61.5	1918	2030

of Hatfield [1] pertaining to the viscosity of sludges as concentrated and drawn and shows more clearly the effect of solids concentrations. The results selected for illustration in Fig. 2 were obtained before the suction lines in the centrifugal pumps were increased in size and clean-out facilities for the prompt removal of stoppages were available.

Only those loadings which were not noticeably interrupted by stoppages were used for the illustration. Examination of the corresponding loading rates for these concentrations does not show a direct relation between the prevailing head and loading rates, nor a direct relation between solids concentration increases and loading rates. This may be caused by other factors which may overbalance the solids concentration effect, because even at almost constant temperature and approximately the same solids concentration there may be appreciable

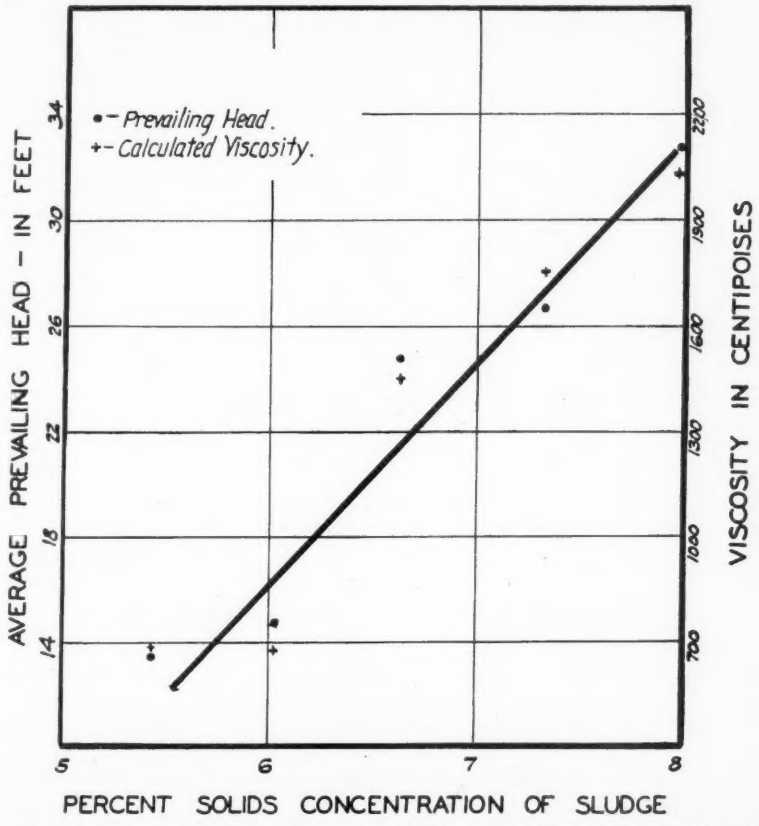

FIG. 2.—Relation between prevailing head and calculated viscosities with increasing solids concentration.

variations in the loss of head, loading rates and calculated viscosities. Some examples are given in Table III for different runs. In some of these runs temporary difficulties, minor changes in method of operation, partial change in type of sludge, etc., resulted in variations in loading time, more or less effective cleaning of pipe line and subsequent variations in head and calculated viscosities. Nevertheless, it can be observed that the calculated viscosities were between 1,000 and 2,000 centipoises.

In an effort to determine whether there was a relation between solids concentration and loading rates, results obtained at about the same temperatures with varying solids concentrations were grouped in

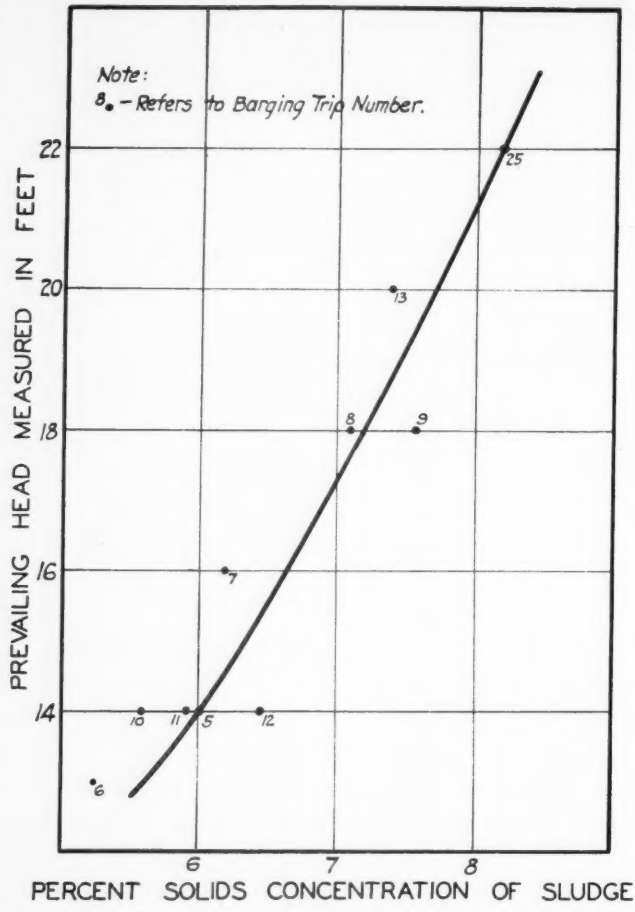

FIG. 3.—Relation between solids concentration and loss of head at about constant temperatures (66–70° F.).

TABLE III.—*Variation in "Viscosity" at Almost Constant Temperatures and Approximately the Same Solids Concentration*

Barging No.	Temp., ° F.	Head, Ft.	Solids, %	Ash, %	Rate, G.p.M.	Velocity, S.F.	Viscosity, C.P.
13	64	20	7.39	25.9	2420	1.72	1000
14	62	22	7.32	23.5	1940	1.37	1470
23	61	28	7.23	28.9	2340	1.66	1450
24	62	28	7.32	23.4	1895	1.34	1850
45	61	40	7.82	24.1	1300	0.92	2000

ascending order of solids concentrations (Table IV). The grouping does not indicate that there is a direct relation between total solids concentration and rate of loading within narrow limits. However, when we look at the groups of bargings at approximately the same tem-

TABLE IV.—*Relation Between Total Solids and Rate of Loading at About Same Temperatures*

Temp., ° F.	Total Solids, %	Rate, G.p.M.	Velocity, S.F.	Head, Ft.	$\Delta H/100$ Ft.	Calc. Viscosity, C.P.
48	6.57	1320	0.945	34	0.772	3150
50	7.20	1500	1.064	34	0.772	2800
52	7.29	1600	1.136	34	0.772	1820
55	6.40	1760	1.250	28	0.637	1980
54	6.80	1290	0.915	30	0.682	2980
55	7.19	1000	0.710	34	0.772	4220
67	5.59	2435	1.730	14	0.318	725
66	6.45	3320	2.260	14	0.350	545
67	8.19	1990	1.414	22	0.500	1380
70	5.24	2610	1.855	13	0.295	620
70	6.00	2640	1.875	14	0.318	660
70	6.18	2925	2.090	16	0.363	670
70	7.57	2435	1.730	18	0.408	915
72	6.76	2875	2.04	16	0.363	690
73.5	7.61	2380	1.62	18	0.408	975
73.5	8.07	2805	1.99	18	0.408	800
72	8.35	2970	2.11	18	0.408	750

perature and disregarding the solids concentrations, the velocities, loss of head and viscosities seem to fall into two groups, namely those between temperatures of 48–55° and temperatures between 66 and 73.5° F. This break or change is more clearly indicated when the groups are averaged (Table V). It appears therefore, that if the rate of load-

TABLE V.—*Calculated Average Viscosities, Loss of Head and Velocity of Flow at Two Temperature Ranges*

Temp., ° F.	Velocity, S.F.	Loss of Head/100 Ft. Pipe, Ft.	Calculated Viscosity, C.P.
48–55	1.003	0.701	2825
66–73.5	2.087	0.374	794

ing is affected by sludge characteristics a factor other than sludge concentration, or a combination of factors in which sludge concentration is a part is of greater importance. The remarkable drop in loss of head at the higher temperatures, shown in a different way by the increased velocity in flow and the reduction in apparent viscosity seems to be of much greater magnitude than the variations in sludge concentration.

It should be kept in mind that the average results shown in Table V are based upon approximately the same average solids concentrations. In connection with the loading rates recorded, it should be understood that the loading rate as expressed in gallons per minute is affected by stoppages in the line, or any other trouble which may occur during loading. The loading rate indicates only the time elapsed for a given amount of sludge barged irrespective of time required to overcome the difficulties. For that reason the average increase in head is a better measure to determine the effect of the various factors than average rates of loading.

Temperature.—To obtain further information regarding the possible effect of the temperature of the sludge on friction losses the results were grouped in accordance to narrow temperature ranges and the prevailing heads, total solids, loading rates and velocities averaged for the same batches of sludge (each batch from 2,900 to 3,500 tons). The average results are shown in Table VI. The average solids con-

TABLE VI.—*Relation Between Temperature and Head*

Number of Bargings	Temp. Range, ° F.	Ave. Temp., ° F.	Ave. Prevailing Head, Ft.	Ave. Total Solids, %	Rate of Flow, G.p.M.	Loss of Head per 100 Ft., Ft.	Velocity, S.F.
5	52–53	52.4	39.6	7.80	1703	0.900	1.22
5	54–55	54.6	34.4	7.42	1340	0.782	0.99
5	57–58	57.4	31.2	6.94	1840	0.709	1.32
3	61	61.0	29.3	7.40	2398	0.666	1.71
3	62–64	62.7	23.3	7.34	3127	0.530	2.23
5	66–67.5	67.0	16.4	6.70	2535	0.373	1.81
8	69–70	69.6	16.6	7.19	2497	0.373	1.78
5	72–73.5	72.6	17.6	7.67	2693	0.400	1.92

tent for each group of sludge batches was fairly constant, varying from 6.70 to 7.80 per cent. The changes in prevailing head are plotted against the average temperatures in Fig. 4. There seems to be a definite relation between the temperature and the prevailing head, the lower the temperature the higher the friction.

The next question was whether the sludge concentration factor is of equal or less importance than the temperature effect. To obtain an idea in this respect the individual results for the year 1937–38 were plotted, but the solids concentrations disregarded. The results shown in Fig. 5 give a clear indication of the effect of temperature.

When the loss of head per 100 ft. of pipe line is plotted against the velocity of flow on log-log paper the effect of temperature is even more clearly shown. The individual results obtained at the same temperatures shows straight lines of *positive* slope with increasing head at increasing velocities. However, when the averaged data for different temperatures (Table VI) are plotted a fairly straight line of *negative* slope is obtained, in other words, with increased temperatures a decreasing head at increasing velocities is obtained, which seems to indi-

cate that the temperature effect so greatly reduces the "viscosity" of the sludge as to overcome entirely the normal velocity effect. Close examination of the results seems to indicate that the temperature effect is of greatest importance up to 65° F. At temperatures lower than 65° F. the head loss decreases rapidly with increasing temperatures, but above 65° F. the changes are nominal, in other words, above this temperature the sludge concentration or other factors would possibly exert

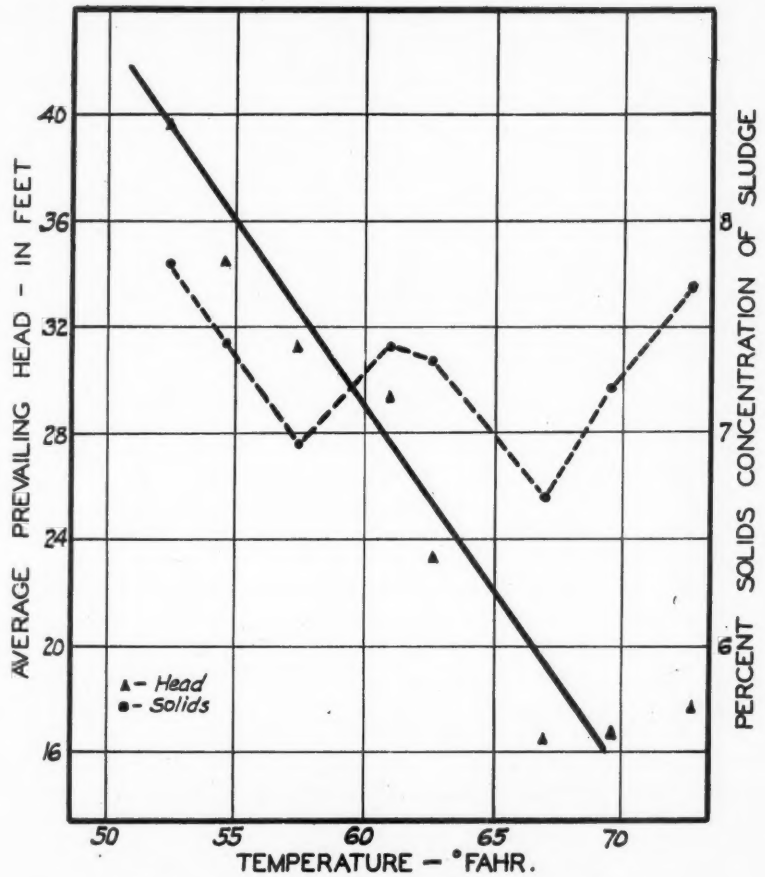

FIG. 4.—Effect of temperature of sludge on loss of head.

a greater effect than temperature. However, if the results presented in Tables IV and V are considered it becomes clear that the viscosities of the sludge are such that they are still in the viscous or straight line flow region, although greatly reduced at the higher temperatures.

It has been shown by Hatfield [1] that sludges have the property of losing a considerable portion of their apparent viscosity on agitation or stirring. This would indicate that increased pump capacities could produce velocities in the turbulent flow region at these higher tempera-

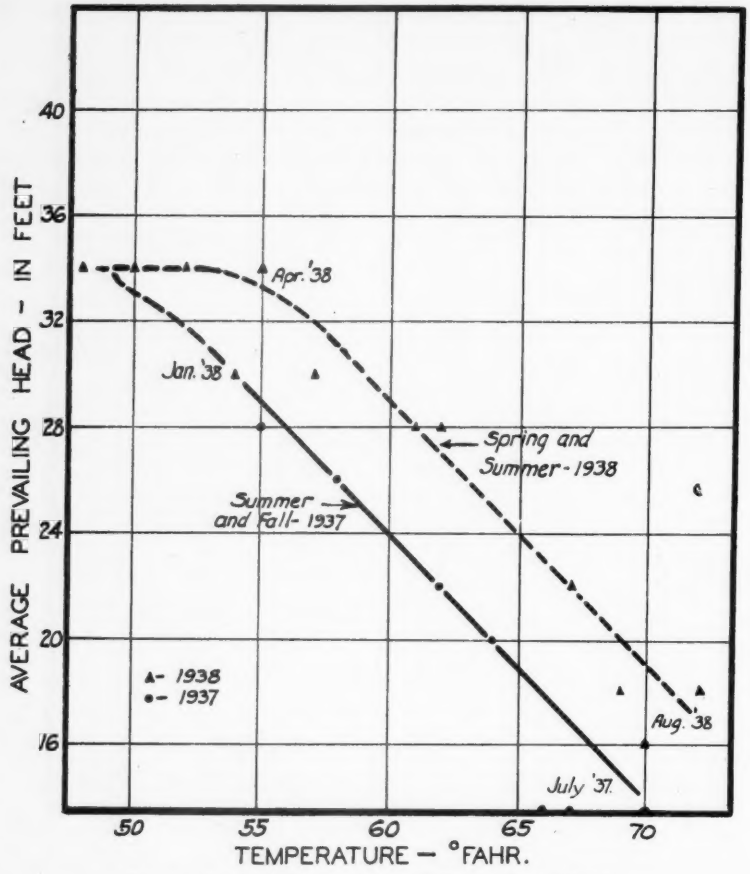

FIG. 5.—Seasonal effect of temperature on loss of head.

TABLE VII.—*Relation Between Ash Content and Rate of Loading at About Same Temperature and Solids Concentration*

Barging No.	Ash, %	Rate, G.p.M.	Temp., ° F.	Total Solids, %	Velocity, S.F.
26	24.2	1960	69	8.41	1.40
27	30.2	2520	70	8.07	1.80
29	36.6	2805	73.5	8.07	2.00
28	40.1	2970	72	8.35	2.12

tures without increasing the head, or even lowering the head on account of reduction in viscosity.

Another approach would be to employ an effective method of stirring or agitation in the sludge at the time the sludge is pumped, allowing a higher rate of pumping and subsequently approaching or attaining a turbulent flow in the pipe line. Such a method would presumably be relatively more effective at lower temperatures than at higher tem-

peratures, but would have the tendency to equalize barging time in winter and summer.

Still another method to increase pumping rates in winter would be by temperature control, while a combination of stirring and temperature control would be best. Under operating conditions the economics of such procedures would be the deciding factor.

The results presented in Fig. 5 appear to fall within a narrow zone with the head increasing and temperature decreasing. Beginning with a temperature slightly above 70° F. in summer the head increased regularly when the sludge became cooler during fall and winter, decreasing again when the sludge became warmer, but apparently at a somewhat different rate. There appears to be a lag in the temperature effect. The reason for the difference in rate of change in head at the same temperature or lag is somewhat obscure, unless it is assumed that bacterial action resulting in partial liquefaction affects the viscosity sufficient to cause less friction. The lag in bacterial activity during the spring could account for such difference, because in actual operation not all the sludge stored in the tanks can be removed at each barging, so that a portion of the colder sludge remains with somewhat slower bacterial action. If this assumption is correct the same phenomenon should repeat itself and the temperature effect be greater during the next fall and winter season. Unfortunately no direct comparison in this respect could be made because of the change in size of suction pipe and clean out facilities in the early part of the summer of 1938, but the data available indicate a repetition of the previous year with somewhat higher loss of head at the various temperatures. If the effect of liquefaction is of sufficient importance longer storage would be of advantage in this respect. However, another factor would arise, namely the effect of gases entrained in the sludge. Hatfield [1] accidentally discovered that the de-gasification resulted in a large decrease of the apparent viscosity of the sludge, so that many small bubbles held within the sludge increased the viscosity to such an extent that a considerable portion of the temperature effect was overcome. As a matter of fact, Hatfield states that, "An increase in temperature may release gas into the sludge, thus entirely overcoming any reduction in viscosity due to temperature effect alone." To be sure, the remarkable change recorded by Hatfield was brought about by rather rapid heating and cooling of the sludge without a chance to release the small gas bubbles, but increased bacterial action resulting in gasification would conceivably have a similar effect. It would appear therefore, that there is a balance somewhere between time of storage and temperature. Longer storage in summer would result in relatively more difficulties than prolonged storage in winter, although the gross temperature effect in summer is beneficial as compared with winter temperatures. Putting it differently, reduced storage time in summer would allow a still greater loading rate with lower pumping head.

Ash.—The ash contents of the sludges vary usually between 22 and 30 per cent. During June–August, 1938, after the increased suction

and clean-out facilities were available, the average ash content varied from 24.2 to 40.1 per cent, while the temperature and solids concentrations were nearly constant. If the ash content is of importance within these limits the rate of loading should be affected. The results of these four loadings are shown in Table VII. There seems to be a relation between the ash content of the sludge and loading rates.

According to Merkel [2] increases in lyophobic material have no large effect on the viscosity of the sludge, but increase the internal resistance and the yield point. However, it would seem logical that increases in inorganic material such as ash content (probably caused by sand) should affect the gel-like structure of the sludge or the viscosity and hence the friction losses. This is indicated by the fact that the head losses, temperature and solids content were practically constant, while the rate of flow increased with the higher ash content of the sludge.

Summary

During two years operation of raw sludge retained in storage tanks and barged to sea, information was obtained regarding various factors affecting the rate of flow and viscosity of sludge through a 24 inch pipe 4,400 ft. long. The amount of sludge handled in each barging varied from 2,900 to 3,500 tons, loaded at a rate of 1,000 to 3,350 gal. per min. The solids concentration varied from 5.2 to 8.4 per cent, the temperature of the sludge from 48 to 73.5° F., the ash content from 21.4 to 40.1 per cent of the dry solids and the average total operating head on the pumps from 14 to 42 feet.

The results show a material increase in loss of head with increased solids concentration, with the rate of loading and calculated viscosities following the general trend.

The temperature of the sludge exerts a greater influence than solids concentration, the loss of head increasing with decreasing temperature. The temperature effect may overbalance the effect of solids concentration, with the greatest effect up to 65° F. There appears to be a lag of the temperature effect according to season and subsequent flow velocities or barging rates, possibly due to bacterial action causing partial liquefaction of the sludge on storage. The ash content of the sludge appears to affect the gel-like structure of the sludge so that the viscosity and hence the friction losses change, resulting in increased rate of flow with higher ash content.

Acknowledgment

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THE DEVELOPMENT OF SEWAGE OXIDATION BY A TRICKLING FILTER*

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The capacity of a sewage trickling filter to produce a satisfactorily nitrified and stabilized effluent depends upon the development of adequate biologic life in the filter medium. Little information is available regarding the time required for the growth of such biologic forms under operating conditions, and thus of the interval before maximum purification will be obtained. The construction of a new sewage treatment plant for the Albany-Schenectady Road Sewer District provided an excellent opportunity to study this problem. This plant, designed for a population of 4,000 but serving at the time of this study only about 1,500 persons, consists of a comminutor, equipment for pre-chlorination, primary settling tank with separate sludge digestion, a trickling filter 0.22 acre in area and 6 ft. deep, and a secondary sedimentation tank with provision for final chlorination of the effluent. The sewage received is entirely domestic in character, containing no industrial wastes and only a small amount of household laundry wastes.

Sewage was first admitted to the plant December 15, 1937, and for the first week was passed through all units in order to test their construction. During the remainder of the winter months, the filter was by-passed because of the difficulty of starting such a unit in cold weather and also because the flow of sewage at the time was so low that freezing would undoubtedly have resulted in the trickling filter bed.

On January 18, 1938, pre-chlorination of the raw sewage was started and a residual of 0.5 to 0.75 p.p.m. was maintained at all times. On March 2, 1938, the trickling filter was placed in operation, chlorination of the raw sewage being continued to maintain substantial residual values in the sewage applied to the trickling filter. Thus, no biologic growth developed in the medium and no oxidation of the sewage was obtained. On April 18, four days before beginning this investigation, chlorination of the raw sewage was reduced sufficiently to provide no more than 0.05 to 0.1 p.p.m. of residual chlorine in the influent to the primary sedimentation tank; the sewage applied to the trickling filter was thus free from chlorine.

The study was begun April 22, 1938, and continued for 107 days. The flow of sewage varied slightly—April—85,000 gallons per day; May—102,000; June—103,000; July—84,000; August—91,000. At approximately weekly intervals, samples of the trickling filter influent and effluent were collected for complete chemical analysis. At the same time observations were made of the development of biologic life

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on the filter stones, and special samples were collected for microscopic examination.

The sample of the trickling filter influent was a single catch sample taken from the outlet of the dosing tank as it began to discharge to the filter. The effluent sample was collected from the trickling filter effluent drain and was integrated during the time required for one discharge from the dosing tank to pass through the filter, in accordance with the rate of flow in the effluent pipe.

For the first 28 days the sample of effluent was analyzed as collected. During this period solids accumulated in the bed and gradually appeared as suspended material in the filter effluent. To eliminate possible interference by these suspended solids, the effluent sample thereafter was allowed to settle for twenty minutes; the supernatant was siphoned from the settled solids and considered representative of the trickling filter effluent. The results of the chemical analyses are given in Table I and have also been plotted in Figs. 1 and 2 to illustrate the progressive changes in the significant determinations. Figure 1 shows the gradual decrease in the oxygen consumed and biochemical oxygen demand, indicative of oxidation of the organic material present in the effluent. These values fluctuated widely during the study, due probably to variations in the concentrations of the raw sewage, but they show a distinct downward trend for a period of 60 days. Thereafter, the biochemical oxygen demand remained practically constant at about 20 p.p.m. and the oxygen consumed at about 35 p.p.m., values which appear to be as low as can be obtained with this particular plant.

Figure 2 illustrates the progressive changes in the nitrogenous constituents of the filter effluent. The various forms of nitrogen have been expressed as per cent of the total nitrogen in order to eliminate the effect of fluctuations in the total nitrogen content of the raw sewage as received at the plant. At the start of the investigation the ammonia nitrogen was about 80 per cent of the total nitrogen and the organic nitrogen about 20 per cent. No nitrates or nitrites were present. After six days, oxidation of ammonia and organic nitrogen to nitrites and nitrates was detected, and this proceeded slowly for approximately 20 days. Between the 25th and 35th days, the ammonia and organic nitrogen decreased rapidly. The oxidation of these constituents was only partly complete during the first part of this period as shown by the increase of nitrite content until the 31st day. After the 40th day, oxidation of the nitrogenous constituents was nearly complete, so that 75 per cent of the nitrogen was present as mineralized nitrates. Ammonia nitrogen had then been reduced to about 15 per cent and organic nitrogen to about 3 per cent of the total.

The biologic forms found on microscopic examination of the bacterial slime near the surface of the filter are listed in Table II. They have been classified so that those at the top are, in general, typical sewage microorganisms, tolerant of heavy pollution. Passing down the list, the types progressively less tolerant of pollution are given, until at the bottom are shown organisms whose normal environment is

TABLE I.—*Results of Analyses of Samples of Influent and Effluent*

Date of Collection	4/22/38		4/25/38		4/28/38		5/2/38		5/5/38		5/10/38		5/12/38		5/16/38		5/20/38		5/23/38	
	Infl., p.p.m.	Effl., p.p.m.	Infl., p.p.m.	Effl., p.p.m.	Infl., p.p.m.	Effl., p.p.m	Infl., p.p.m.	Effl., p.p.m.	Infl., p.p.m.	Effl., p.p.m.	Infl., p.p.m.	Effl., p.p.m.	Infl., p.p.m.	Effl., p.p.m.	Infl., p.p.m.	Effl., p.p.m.	Infl., p.p.m.	Effl., p.p.m.	Infl., p.p.m.	Effl., p.p.m.
Free ammonia	35.0	30.0	36.0	35.0	38.0	36.0	39.2	33.6	34.1	31.3	44.8	30.8	50.4	33.6	25.2	16.8	25.2	12.6	26.6	2.8
Organic nitrogen	9.8	5.6	12.3	7.4	12.0	7.0	19.3	10.9	25.4	13.2	17.8	11.9	13.6	8.8	11.2	6.0	17.2	4.2	21.4	2.5
Nitrite nitrogen	0.08	0.08	0.06	0.08	0.06	0.16	0.008	0.4	0.008	0.4	0.008	0.7	0.002	0.8	0.8	1.6	0.05	5.0	0.002	8.0
Nitrate nitrogen	0.26	0.10	0.24	0.24	0.08	0.64	0.04	2.8	0.04	3.52	0.06	4.0	0.04	7.0	1.0	7.0	0.14	8.6	0.04	17.9
Oxygen consumed	140	85	112	57	135	70	130	70	122	65	170	90	150	50	75	45	85	55	85	35
Chlorides	49	46	54	54	51	51	54	57	58	57	59	58	61	62	43	41	52	52	55	55
Dissolved oxygen		6.6		6.8		6.7		7.2		6.1		5.6		5.2		7.6		6.3		5.6
B.O.D., 5 day	145.6	66.5	>152	51	24.4	48	225	43	248	64	350	95	258	65	124	45	150	94	221	345
Total solids	576	463	558	495	581	480	568	482	598	527	680	558	614	531	511	465	505	487	533	495
Ignited solids	293	215	295	218	331	206	343	254	353	252	408	322	295	188	162	119	150	110	202	108
Fixed solids	283	248	263	277	250	274	225	228	245	275	272	236	319	343	349	346	355	377	331	387
Dissolved solids	494	405	499	446	521	448	513	448	501	483	620	498	540	495	437	443	466	456	486	486
Ignited solids	233	176	249	189	283	186	301	233	272	228	360	278	238	167	110	108	113	94	159	99
Fixed solids	261	229	250	257	238	262	212	215	229	255	260	220	302	328	327	335	353	362	327	387
Suspended solids	82	58	59	49	60	32	55	34	97	44	60	60	74	36	74	22	39	31	47	9
Ignited solids	60	39	46	29	48	20	42	21	81	24	48	44	57	21	52	11	37	16	43	9
Fixed solids	22	19	13	20	12	12	13	13	16	20	12	16	17	15	22	11	2	15	4	0
Temperature, °C	10°	12°	10°	11°	12°	12°	15°	13°	13°	13°	14°	13°	13°	12°	12°	11°	13°	13°	15°	15°
pH	7.5	7.9	7.5	7.9	7.4	7.7	7.3	8.1	7.3	7.7	7.2	7.5	7.1	7.7	7.3	7.9	7.2	7.3	7.3	7.5

TABLE I.—*Continued*

Date of Collection	5/26/38		5/31/38		6/6/38		6/9/38		6/13/38		6/23/38		6/30/38		7/7/38		7/21/38		8/5/38	
	Infl., p.p.m.	Effl., p.p.m.	Infl., p.p.m.	Effl., p.p.m.	Infl., p.p.m.	Effl., p.p.m.	Infl., p.p.m.	Effl., p.p.m.	Infl., p.p.m.	Effl., p.p.m.	Infl., p.p.m.	Effl., p.p.m.	Infl., p.p.m.	Effl., p.p.m.	Infl., p.p.m.	Effl., p.p.m.	Infl., p.p.m.	Effl., p.p.m.	Infl., p.p.m.	Effl., p.p.m.
Free ammonia.....	31.4	4.2	39.6	4.3	42.0	5.6	36.5	7.2	42.0	6.0	47.6	5.0	40.6	2.5	39.6	4.8	42.4	3.5	35.0	1.8
Organic nitrogen..	15.2	0.7	23.1	1.0	12.6	1.6	28.6	0.7	17.3	0.3	20.5	0.6	18.9	1.0	23.4	1.0	19.2	0.6	8.8	1.7
Nitrite nitrogen...	0.002	4.0	0.002	2.0	0.002	2.0	0.002	2.0	0.001	0.8	0.001	0.8	0.002	0.5	0.001	0.8	0.002	1.0	0.001	0.8
Nitrate nitrogen...	0.04	14.0	0.04	25.6	0.04	29.6	0.04	30.0	0.06	25.0	0.08	14.0	0.04	19.2	0.04	28.0	0.04	20.0	0.16	12.8
Oxygen consumed .	115	50	130	45	130	45	125	60	115	50	100	30	120	30	130	35	120	45	115	35
Chlorides.....	52	51	59	61	60	62	63	64	48	53	56	55	58	54	64	62	56	53	33	35
Dissolved oxygen..		6.2		5.6		3.9		3.9		4.8		4.1		5.5		5.2		4.8		5.2
B.O.D., 5 day.....	340	27	390	43	278	47	270	31	250	28	247	17	290	17	267	21	220	23.3	202.5	8.0
Total solids.....	570	510	669	592	610	655	628	622	586	600	641	647	694	580	652	612	747	605	609	506
Ignited solids .	192	152	318	180	268	268	264	200	254	252	302	275	301	173	274	212	359	214	234	154
Fixed solids...	378	358	351	412	342	387	364	422	332	348	339	372	393	407	378	400	388	391	375	352
Dissolved solids...	511	501	591	576	545	630	542	596	531	577	594	632	634	574	579	600	700	591	402	491
Ignited solids .	141	145	252	169	214	253	183	184	210	239	260	260	245	167	220	207	319	206	158	146
Fixed solids...	370	356	339	407	331	377	359	412	321	338	334	372	389	407	359	393	381	385	244	345
Suspended solids ..	59	9	78	16	65	25	86	26	55	23	47	15	60	6	73	12	47	14	207	15
Ignited solids .	51	7	66	11	54	15	81	16	44	13	42	15	56	6	54	5	40	8	76	8
Fixed solids...	8	2	12	5	11	10	5	10	11	10	5	0	4	0	19	7	7	6	131	7
Temperature, °C...	15°	14°	16°	16°	17°	18°	16°	16°	19°	19°	23°	22°	19°	19°	20°	20°	21°	21°	23°	23°
pH.....	7.3	7.5	7.2	7.5	7.2	7.1	7.3	7.3	7.3	7.7				7.5	7.1	7.3	7.1	7.5		

clean water. Such an arrangement is of necessity more or less arbitrary. Many species are tolerant of fairly wide ranges of pollution and could be raised or lowered in the column without altering their significance. The extremes of the column are correct however. Plotted against the list is a series of marks representing the time in days after the filter was started when each organism was found in the zoogleal growth.

These results show that for 20 days after the filter was placed in operation only typical sewage organisms were found on the filter; they

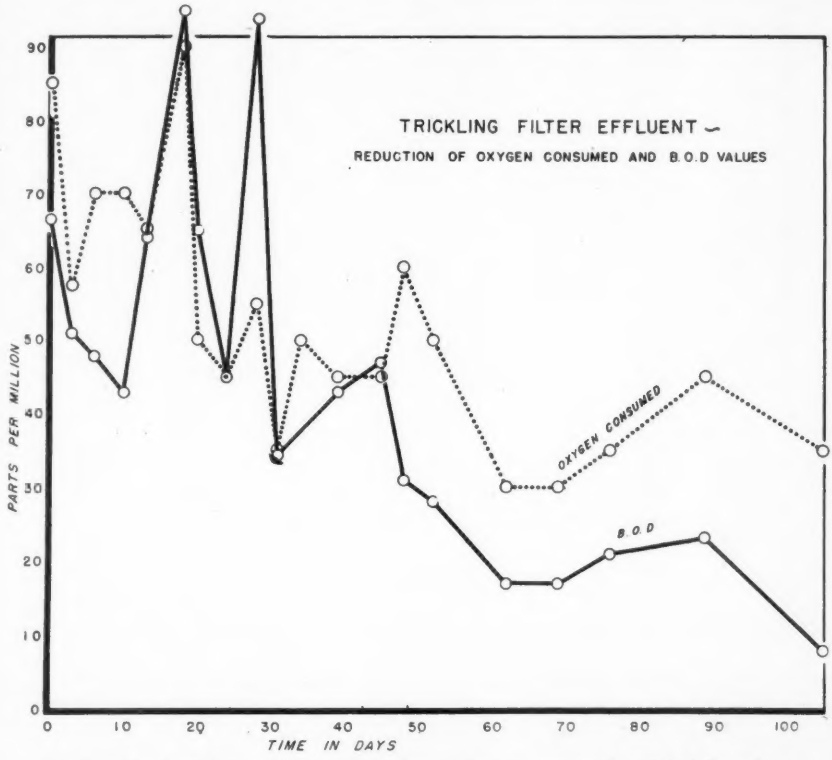


FIG. 1.—Trickling filter effluent. Reduction of oxygen consumed and B.O.D. values.

were probably present in the sewage itself. Also characteristic of raw sewage is the fact that only a few types of organisms were found, although present in large numbers. From the 20th to the 40th day there was a slight increase in the species less tolerant of heavy pollution. Between the 40th and 50th days the variety of organisms increased and those tolerant of only a small amount of putrescible matter were present. After the 50th day, the distribution covered the entire range of purification, indicating that the sewage had been purified to such an extent that organisms whose normal environment is clean water began to appear.

The visual observations made at the time the samples were collected indicated that very little zoogleal growth had developed on the filter during the first 20 days. From the 20th to the 30th day, it gradually developed over the entire bed and from then to the 40th day it became increasingly heavy. About the 45th day the growth had become so heavy that it began to slough off the filter medium and appear in the effluent.

The results of this study indicate that after a lapse of 60 days this trickling filter attained its maximum capacity for the oxidation of the

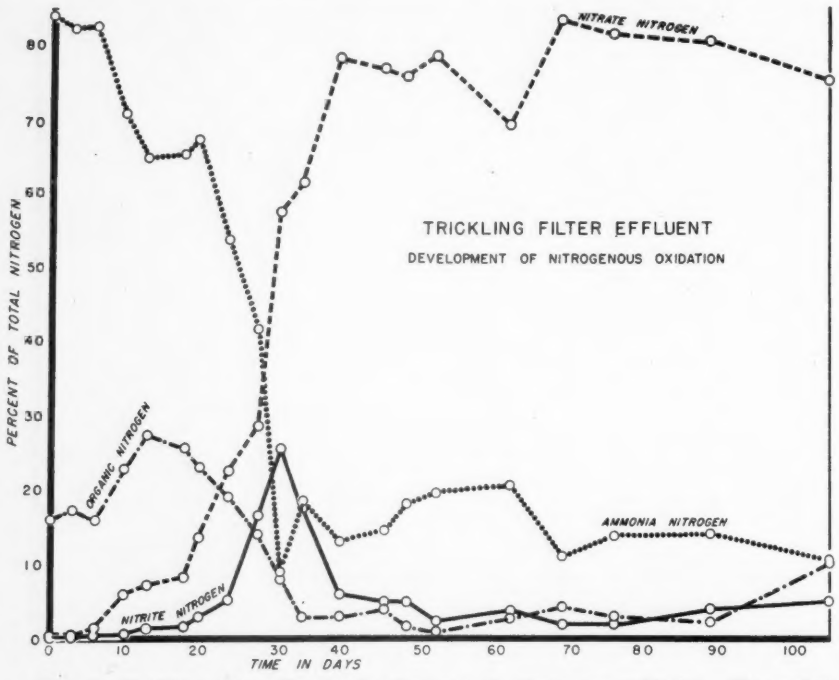


FIG. 2.—Trickling filter effluent. Development of nitrogenous oxidation. The various forms of nitrogen have been expressed as per cent of the total nitrogen in order to eliminate the effect of fluctuations in the total nitrogen content of the raw sewage as received at the plant.

settled sewage applied. Under other conditions, however, the time required might have varied markedly. During the period of the investigation the flow of sewage was very low and the rate of application to the filter was only approximately 400,000 gallons per acre per day or about 25 per cent of the usual rate of application of settled sewage to a trickling filter. The sewerage system had only recently been constructed and the number of house connections was limited. In addition, the per capita flow reaching the treatment plant was small, about 60 gallons per capita per day, which probably explains the high concentration of organic matter in the sewage. During periods of storm, infiltration of ground water into the sewer system caused temporary in-

TABLE II.—*Microscopic Organisms in Zoogleal Growth of Trickling Filter*

Name	Time of Appearance—Days																
	10	20	30	40	50	60	70	80	90	100	110						
Sewage organisms																	
Sphaerotilus	x x	x x x	x x x	x x x	x x x	x	x x	x x	x		x						
Cidpidium	x x	x x	x x x	x x x	x	x	x	x			x						
Vorticella	x x	x x	x x x	x x x	x	x	x		x		x						
Paramecium							x	x									
Pleurotricha				x x													
Colpoda				x	x		x										
Purification organisms																	
Chilomonas	x x	x	x	x x x													
Oscillatoria		x		x x x	x												
Arcella		x	x x	x x x	x x	x	x	x	x		x						
Nematodes			x	x	x x	x	x	x									
Euglypha						x	x										
Lionotopsis						x		x	x		x						
Monas							x										
Chironomus							x										
Psychoda larvae					x		x		x								
Chaenia																	
Trinema					x												
Zoothamnion							x	x	x		x						
Actinophrys							x										
Euglena								x	x		x						
Molds						x			x		x						
Synedra						x	x										
Closterium					x	x											
Carchesium									x		x						
Chlorococcus																	
Nauicula					x						x						
Philodina									x								
Synchaeta								x									
Clothriz								x			x						
Chlamydomonas							x										
Stigeoclonium							x				x						
Amoeba																	
Chlorida								x			x						
Clean-water organisms																	
Diurella							x										
Diffugia					x x	x											
Coelastrum						x	x	x									
Desmida									x								
Blakeothrix								x									
Cydoidda								x									
Damp-rock organisms																	
Palmellococcus				x			x				x						
Protococcus						x	x										

creases in the rate of flow. An increased rate of application to the filter or changes in the strength of the sewage, including admixture with industrial waste, would undoubtedly have affected the time required for complete development of the filter, but whether this would have resulted in shortening or lengthening the period can not be determined from the results of this investigation.

The study was commenced in April and continued through the summer periods of increased temperature. The temperatures of the sewage ranged from 10° to 23° C. If the operation of the filter had been begun during a warmer period, the time required for the development of biologic life might have been shortened considerably. No study was made of the effects of customary operating cycles of the filter, but it is possible that when it became thoroughly seeded with biologic life, treatment of the influent with chlorine would not seriously impair its oxidizing capacity. However, experience with this plant has indicated that if chlorinated sewage is applied to a filter in which no biologic life has previously developed, none will appear in the filter medium.

Summary

To determine the length of time required for a sewage trickling filter that received the effluent of a primary sedimentation process treating domestic sewage to reach maximum efficiency, a study of the progressive oxidation of the sewage was conducted for a period of 107 days. Complete chemical and biologic analyses of samples of influent and effluent were made semi-weekly or bi-weekly. The results indicate that in this particular plant and with settled domestic sewage at the temperatures received, there was a gradual increase in the degree of oxidation of the organic and nitrogenous matters coincident with the gradual development of the biologic life. Approximately 50 days were required for total development of the fauna and flora characteristic of trickling filters; 60 days for maximum reduction of carbonaceous organic matter; and 40 days for complete oxidation of nitrogenous compounds.

I. THE RICHMOND–SUNSET SEWAGE TREATMENT PLANT *

By B. Benas

Superintendent

Previous to the improvements made under the 1933 Sewer Bonds unsanitary conditions existed along the bay and ocean shores, as evidenced by pollution on the shores, the appearance of sewage fields off shore and the results of bacterial tests. This pollution was due to the discharge of untreated sewage from a number of outlets at the shore, which pollution was carried back and forth by the tides, resulting in unsanitary conditions along the shore waters.

The Bureau of Engineering recognized this condition and had for a number of years made preliminary studies but no funds were available to make complete studies or to formulate definite programs of which construction would be a part. Accordingly, when the funds became available under the 1933 Sewer Bonds, a board of consulting sanitary engineers consisting of the late Harrison P. Eddy of Boston, Professor Charles Gilman Hyde of the University of California, Mr. Clyde C. Kennedy of San Francisco and Professor Leon B. Reynolds of Stanford University was appointed to make the necessary studies and recommendations. This board reported in May, 1935, substantially as follows:

> That the number of outlets discharging sanitary sewage in the bay be reduced and that the sewage of the various districts be combined for treatment and disposal so that no untreated sewage would be discharged at any point along the bay or ocean fronts.

Plan of Collection

In order to accomplish this it was recommended that sewage from the districts in the southeast portion of the city be treated at treatment plants located at Visitacion Valley and Hunters Point, and that sewage of the main portion of the easterly slope comprising the North Point and Marina districts be treated at a plant to be located at North Point, and that the treated sewage be discharged approximately 2000 ft. off the shore in 60-ft. depth of water; that the Marina Pumping Plant and force main be constructed to pump the sewage from the Marina district to North Point; that the sewage of the westerly slope of the city, comprising the Baker's Beach or East Richmond district, West Richmond and Sunset districts, be conveyed to and treated at the Richmond-Sunset Sewage Treatment Plant, to be located in the southwest portion of Golden Gate Park; that as much as needed of the effluent be furnished for use in the park, and that the remainder be discharged

* Presented at the Twelfth Annual Fall Convention of the California Sewage Works Convention, Oakland, Sept. 18, 1939.

into the existing Mile Rock trunk sewer to the present outlet at the north shore a short distance eastward of Lobos Point, and that the sludge be digested and dewatered on vacuum filters and furnished for use in the park, upon municipal golf courses and other areas.

It was not possible under the bond issue to complete the whole program, and as the north shore and Great Highway are the main recreational areas at present, works were constructed towards the improvement of these areas as follows:

The Marina Pumping Plant and discharge sewer which pumps the sewage from the Marina district to North Point was built, thereby eliminating the direct source of pollution at the Yacht Harbor. In addition, the United States Government made provision for and are constructing works to discharge the sewage from Fort Mason and the Presidio into the connecting sewers to the Marina Pumping Plant.

The Richmond sewer tunnel and the Richmond connecting sewer which carry the sewage from the Baker's Beach and West Richmond districts to the Richmond-Sunset Sewage Treatment Plant, and the plant itself were constructed, thereby eliminating the direct pollution caused by the discharge of untreated sewage at the Baker's Beach and Mile Rock outfalls.

For the Richmond-Sunset Sewage Treatment Plant studies were made of the population, flows and sewage characteristics for the tributary area. These studies showed that there was a population of 130,000 in the 1930 census, which would increase to 310,000 as an ultimate figure, and that the average flow for the West Richmond and Sunset districts was approximately 60 gal. per cap. per day and somewhat higher in the Baker's Beach district. The flows varied throughout the day, with a maximum of 1.6 times the average and a minimum of approximately 0.25 of the average. The tests indicated that the sewage would have an average strength of approximately 360 p.p.m. suspended solids and that the volatile matter was approximately 80 per cent of the suspended solids.

Design of Plant

The plant was originally designed for a flow of 15 m.g.d. corresponding to a tributary population of 200,000, with provision for additional units to double this capacity when and if required due to the increase of population and flow.

In determining the degree of treatment required, it was necessary to take into consideration the diluting value of the ocean waters into which the sewage was discharged. Accordingly, the plant was designed to remove large floating material, grit and grease, and suspended solids, and for the addition of chlorine for odor control at all times and bacterial disinfection during the time when the beaches are in use, and for digestion of the screenings, grease scum and sludge, and elutriation and filtration of the digested sludge.

The treated effluent is discharged to the Mile Rock sewer and the filtered sludge given to the park to be used as fertilizer. No provision was made in the original plant layout for an activated sludge plant to treat some of the effluent for park purposes, or for a dehydrator plant to dry the sludge from approximately 75 per cent as it discharges from the vacuum filter to approximately 5 to 10 per cent moisture content.

The design of the plant for 15 m.g.d. capacity called for four grit-grease tanks, four mixing and sedimentation tanks, two vacuum filters, and a multi-stage digestion system, but it was necessary to eliminate two grit-grease tanks, two mixing and sedimentation tanks, one vacuum filter, and the secondary digester of the multi-stage digestion system due to lack of funds.

The plant provides for the following (Fig. 1):

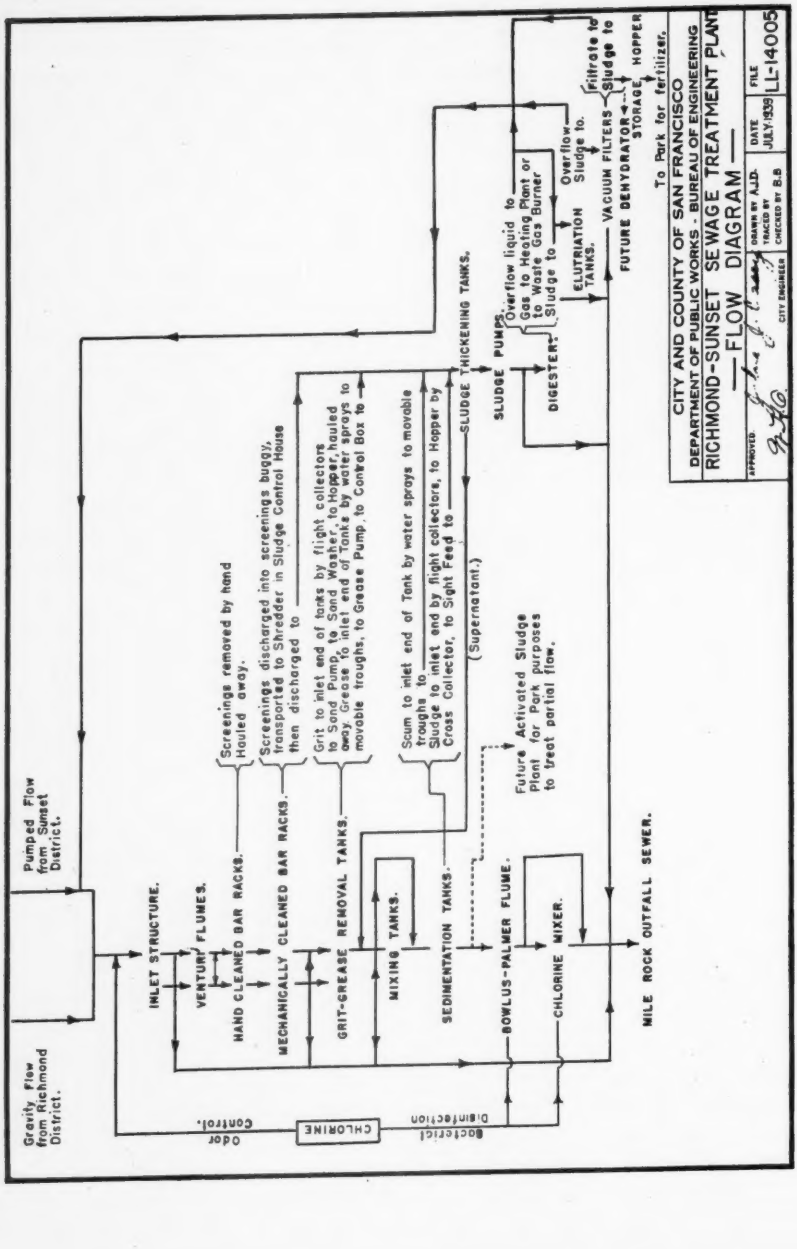
(*a*) Measurement of incoming flow by three-function water level recorders off of 3 ft. venturi flumes.

(*b*) Removal of floating material by hand cleaned bar racks, 4 in. opening, and mechanically cleaned bar racks, ¾ in. opening, the screenings being dumped into screening buggies, transported by hand to the sludge control house, ground by a screenings grinder and deposited into the sludge thickening tanks.

(*c*) Removal of grit and grease in aerated Imhoff type tanks, 12 ft. wide by 50 ft. long, 10-min. holding time at average flow, the grease being carried to the inlet end of the tank by water sprays to a movable trough to a sump and pumped to the sludge thickening tanks in the sludge control house. The sand is carried to the inlet end of the tanks by grit collectors and pumped to a sand washer and the washed sand discharged into a hopper from whence it is loaded in a truck and then deposited in the Park. The organic return from the sand washer discharges into the influent channel to the tanks.

(*d*) Mixing of the effluent from the grit-grease tanks by horizontal mechanical flocculators, 33 ft. 6 in. by 33 ft. 6 in. by 10 ft. water depth divided into four bays, without the use of chemicals, 30-min. holding time for the average flow, and plain sedimentation of the mixed sewage in rectangular tanks 33 ft. 6 in. by 100 ft. 0 in. by 10 ft. water depth, 1.5 hour holding time for the average flow, and discharging of the effluent over four slotted troughs, and with provision for by-passing of the mixing tanks or the use of one or two mixing tanks with one or two sedimentation tanks. The scum is moved by water sprays to the inlet end of the sedimentation tanks to a movable trough to the sludge thickening tanks. The sludge is removed from a deep sump at the inlet end of the sedimentation tanks to the sludge thickening tanks either through sight feeds or directly to the tanks or to the sludge pumps.

(*e*) Thickening of the combined ground screenings, grease and sludge in one of two tanks, capacity 17,500 gal. each, the supernatant


Gravity Flow from Richmond District.
Pumped Flow from Sunset District.
INLET STRUCTURE.
VENTURI FLUMES.
HAND CLEANED BAR RACKS.
MECHANICALLY CLEANED BAR RACKS.
GRIT-GREASE REMOVAL TANKS.
MIXING TANKS.
SEDIMENTATION TANKS.
BOWLUS-PALMER FLUME.
CHLORINE MIXER.
NILE ROCK OUTFALL SEWER.
Odor Control.
CHLORINE
Bactericidal Disinfection
Screenings removed by hand Hauled away.
Screenings discharged into screenings buggy, transported to Shredder in Sludge Control House then discharged to
Grit to inlet end of tanks by flight collectors to Sand Pump, to Sand Washer, to Hopper, hauled away. Grease to inlet end of tanks by water sprays to movable troughs, to Grease Pump, to Control Box to
Scum to inlet end of Tank by water sprays to movable troughs to
Sludge to inlet end by flight collectors, to Hopper by Cross Collector, to Sight Feed to
(Supernatant.)
Future Activated Sludge Plant for Park purposes to treat partial flow.
SLUDGE THICKENING TANKS.
SLUDGE PUMPS.
DIGESTERS.
Overflow liquid to
Gas to Heating Plant or to Waste Gas Burner
Sludge to
ELUTRIATION TANKS.
Overflow
Sludge to.
VACUUM FILTERS
Filtrate to
Sludge to
FUTURE DENYDRATOR
STORAGE HOPPER
To Park for fertilizer.
CITY AND COUNTY OF SAN FRANCISCO
DEPARTMENT OF PUBLIC WORKS - BUREAU OF ENGINEERING
RICHMOND-SUNSET SEWAGE TREATMENT PLANT
— FLOW DIAGRAM —
APPROVED:
CITY ENGINEER
DRAWN BY A.J.D.
TRACED BY
CHECKED BY B.B
DATE JULY 1939
FILE LL-14005

being returned to the influent channel to the mixing tanks and the thickened sludge pumped to the digester.

(*f*) Chlorination of the raw sewage ahead of the plant for odor control and to the final effluent for bacterial disinfection during the time when the beaches are in use by vacuum type automatic chlorinators, both feeds being automatically controlled by converters set in stilling wells off of the influent and effluent measuring flumes.

(*g*) Digestion of the sludge in the 80 ft. diameter by 30 ft. sludge depth primary unit of a two-stage sludge digestion process with turbo mixers, heating coils and stationary steel dome.

(*h*) Elutriation of the digested sludge in two rectangular tanks, approximately 14 ft. 6 in. by 50 ft. by 9 ft. water depth, using the Genter Counter-Current Elutriation System, holding time of each tank 2.0 hours based on a flow of 400 gal. per min. total sludge and elutriating water, together with necessary mixing tanks, sludge pump, meters, etc.

(*i*) Filtration of the elutriated sludge by a vacuum filter, 200 sq. ft. filter area, with bucket elevator feed for the sludge, feeding of ferric chloride in proportion to the feed of the bucket elevator, conditioning of the treated sludge, and automatic regulation of the conditioned sludge feed to the filter.

(*j*) Handling of the filtered sludge by a 24 in. horizontal rubber belt conveyor feeding to a 24 in. inclined troughing rubber belt conveyor to a 24 in. horizontal rubber shuttle belt conveyor discharging into hoppers holding approximately six cu. yd. each.

(*k*) Pumping of the Sunset sewage in the Sunset pumping station by one sewage pump, maximum capacity 800 g.p.m., single speed, 850 r.p.m., and two sewage pumps maximum capacity each 4000 g.p.m., two speeds, 695 and 870 r.p.m., with control of incoming flows by a basin level regulator and shut-off valve and measurement of pumped discharge by three-function recorder off of an orifice, and with special provision for collecting, pumping, washing and storing of the sand collected in the sump.

In addition, the plant provides for heating of the Digester and the Main Building by either sewer or natural gas, and contains a laboratory, storeroom, machine ship, shower and locker room, and office.

Units of Plant

The plant consists essentially of the following units, the dimensions given being approximate:

Pre-Treatment Building.—A two and three-story building 54 by 120 ft., housing venturi flumes and recorders, bar racks, chlorine storage room and chlorinators, sand washer and sand storage hopper, grit and grease removal tanks, and equipment.

Sludge Control House.—A two and three-story building 25 by 40 ft., housing sludge thickening tanks, sludge handling equipment and shredder for screenings.

Mixing and Sedimentation Building.—Covered tanks 70 by 134 ft. with horizontal mixers, sedimentation tanks with collectors, scum removal equipment and return conduit for two-stage sedimentation.

Primary Digester and Digester Operating House.—A covered storage tank 80 ft. diameter by 30 ft. sides with a one-story house 20 by 26 ft.

Main Building.—Two and three-story building 67 by 130 ft., housing elutriation mixers and tanks, vacuum filter, pumping station, main switchboard, heating plant, machine shop, storeroom, office and laboratory.

Start of Operation

The plant was placed in operation in stages, the sewage from the Richmond District being first run through the bar racks and grit-grease tanks starting March 8, 1939, and then through the bar racks, grit-grease tanks and sedimentation tanks to the Mile Rock outfall starting March 10. Due to repairs to the concrete gate in the diversion structure, the sewage from the Sunset District was not pumped through the plant until April 19.

Until March 19 the sludge from the sedimentation tanks was pumped directly to the Mile Rock sewer, and after that date to the digester. Pre-chlorination only was used until April 15, when post-chlorination was also added. The sludge from the digester was first drawn to the elutriation tanks May 24.

During the first six months of operation most of the plant functions have been operated continuously except for periods of shut-down for repair, cleaning and changes.

Many problems have arisen during this early operating period. We have attempted to obtain data as to the flow, sewage characteristics and as to the quantities of chemicals and sludge that have to be handled. In addition, some work has been done towards the study of the operating conditions to obtain the maximum efficiency of the equipment and of the processes.

Operating Experiences

For the purpose of this paper the operation of this plant has been divided into three main divisions:

1. The problems of control and regulation.
2. Laboratory tests and studies.
3. Operation.

I will attempt to discuss problems of control and regulation, giving the general problem, what studies are required to determine the maximum operating efficiency, what has been done to date and the results obtained. Mr. Fraschina, Assistant Superintendent and Tech-

nician, will discuss the laboratory tests and studies, and Mr. Sotter, Chief Operating Engineer, will discuss operation.

Control of Flows.—Control and knowledge of flows are essential to, proper plant operation. In this plant part of the flow is from the Richmond District by gravity and part from the Sunset District by pumping from the Sunset Pumping Plant in the main building.

There are two diversion structures on the connecting sewer from the Richmond District where the flow from the combined sewer systems to the plant can be controlled or by-passed. A diversion gate on the Mile Rock sewer and inlet control valves on the inlet line from the Mile Rock sewer to the Sunset pump sump control the diversion or by-passing of the Sunset sewage.

The plant was designed to take care of the normal sanitary flow and light summer rains, it being necessary to by-pass the Sunset sewage during times of storm. Chemicals and treatment processes are regulated in accordance with flows so that the proper knowledge and control is of paramount importance.

It was proposed to tabulate and make studies of hourly, daily, and seasonal records to determine possible minimums, maximums and averages for present and future treatment; to determine relations between storm and sanitary flow and effect on hydraulic grade line through the plant; and to set up operating conditions for the use of one or two channels in the pre-treatment building.

Our records to date show that the average daily flow varies from 6.5 to 8 m.g.d., being greater during the week days and less on Saturdays and Sundays. This daily average increases during the school period and decreases during the vacation period. We have not had any opportunity to determine what the winter flow will be but it is assumed that it will probably increase from 10 to 15 per cent over the average summer flow.

There is considerable variation in the daily flow, a peak of approximately 1.75 times the average occurring from 9 to 10 A.M. on week days and from 10 to 12 A.M. on Sundays, and a minimum of approximately 0.25 of the average occurring at 5 to 6 A.M. There is an afternoon low at 5 P.M. which is slightly less than the average, and an evening peak at about 8 P.M. slightly above the average.

Bar Racks.—The bar racks are used to remove large floating particles. As the sewage is from a combined system, a hand cleaned bar rack is placed ahead of the mechanically cleaned bar rack to remove particles which might interfere with the operation of the mechanically cleaned bar rack.

Except when the plant first went into operation, very little material has collected on the hand cleaned bar rack, with the exception of rags at times. However, we have not had any rains which might bring down considerable floating material. The bar racks have been operated continuously and we have removed approximately 3 cu. ft. of screenings per million gallons of sewage. No particular trouble has been experienced in the handling of the screenings by screening bug-

gies, or in the transportation of the screenings to the sludge control house. At times the bar rack has been washed with chlorine solution and some solution added to the screenings for the control of odor.

Grit and Grease Removal.—It is necessary to remove grit as it deposits in the channels and affects the life of the mechanical equipment and interferes with the operation of the digester. The areas tributary to the plant have sand dunes composed of very fine sand, a large proportion being between 1/60 and 1/100 mm. in size. The sand handling problem in this plant is very acute and will be discussed more fully in the operation of the Sunset sump.

Grease increases the scum problem in the sedimentation tank and affects the appearance of the sewage fields offshore. It is essential to remove as much of this as possible, consistent with other operating factors.

In the operation of the grit-grease tanks a number of problems present themselves:

1. The determination of the correct location of the diffuser plate holders to give a transverse flow from flowing through chamber through wickets to the grease collecting chamber.
2. Determination of air requirements as affected by change in volume and strength of sewage to give maximum removal of free grease without liberating grease from suspended solids.
3. Determination of air requirements to give complete removal of sand with minimum removal of organic material.
4. Determination of operating conditions of the sand washer to give removal of sand of smallest size up to 1/100 mm.
5. Determination of best operating conditions for grease pumping and method and interval between cleaning of lines.

Tests were first made for the correct location of the diffuser plate holders and it was found that with one holder located next to the wall and the other with about 6 in. clearance from the first that there was the least tendency to circulate in the flowing-through chamber only and that the holding time in the unit as tested by dyes corresponded to the theoretical holding time.

As will be discussed by Mr. Fraschina, grease removal tests are not always consistent, so that it has been hard to determine what results are being obtained from this unit. Some of the grease liberates in the inlet channel to the sedimentation tanks so that the efficiency can be expressed only in terms of overall removal rather than the removal at the surface of the tank.

No particular trouble has been experienced with the operation of the grease removal system except that at times it is necessary to supplement the water sprays by hand operation with a rake.

When the grease is skimmed off, the inlet valve to that tank is closed and the air supply cut down to a minimum so that the water comes practically to rest, thereby requiring the least force for the

water sprays to move the grease to the inlet end. No trouble has been experienced in the pumping of the grease.

Tests were made of the air requirements and it was found that if the air was applied at the rate of 0.05 cu. ft. per gallon, based on the average flow, the maximum amount of sand was removed with a minimum of organic material. Some fine sand is carried beyond the tanks and collects in the inlet channel to the sedimentation building and in the mixing tanks. This bears some relation to the quantity being pumped over from the Sunset sump and decreases materially after the sump has been cleaned. Tests will be made to determine if this can be completely eliminated by placing another tank in service, thereby reducing the flowing-through velocity by one-third.

The sand pump was originally installed with a 3 h.p. motor, based on pumping a mixture of sand and water of approximately 75 per cent moisture with a velocity of approximately 4.5 ft. per second. Some trouble was experienced in the plugging of the discharge line when slugs of sand got into the pump. This unit has been replaced with a pump having a 5 h.p. motor, so that velocities up to 7 and 8 ft. per second can be obtained. No further trouble has been experienced since the new installation.

The sand washer produces a reasonably clean and dry sand under normal operating conditions. However, during storm conditions or when the Sunset sump is being washed down, some organic material comes over with the washed sand. The quantity of washed sand varies depending upon the operation of the Sunset sump from 0.5 to 3.0 cu. yd. per day. This sand is delivered to the park and used for fill and for composting of sludge.

Mixing and Sedimentation.—The sedimentation tanks remove the particles of suspended solids which will settle by gravity. In this plant, mixing tanks with slow stirring have been added to increase the efficiency of sedimentation without the addition of chemicals. The inclusion of the mixing unit was based on the results of experiments made previous to the design of the plant which showed that it was possible to obtain considerably higher percentage removal of suspended solids with mixing than without, and that the settling curve became much steeper and all of the settleable material would settle in less than an hour. For the most efficient operation of the mixing and sedimentation tanks it was decided that the following tests would have to be made:

Mixing.—1. Determination of the speed of the paddles for best flocculation through operation of variable-speed drive.

2. Check on the holding time in baffled units and study for elimination of short-circuiting if required.

Sedimentation Tanks.—1. Determination of best method of operation based on removal of suspended solids and B.O.D.

(*a*) Mixing—Sedimentation
(*b*) Mixing 1 tank—sedimentation 2 tanks
(*c*) Mixing—sedimentation—mixing—sedimentation.

For each of the above the determination of the maximum flow possible for each process as related to effect on hydraulic grade line.

2. Check on operation of the flight conveyors and determination of time interval of operation through daily cycle.

3. Check on best pressure of nozzles for most efficient operation and spacing to move particles most efficiently to scum trough.

Tests made on the removal of suspended solids for various speeds of the paddle showed that best results were obtained at a speed of 0.8 ft. per second at the periphery, that nearly as good results were obtained at 1 ft. per second at the periphery, and that for higher speeds the percentage removal decreased. A speed of 1 ft. per second is now being used as there is less tendency to deposit material in the baffled mixing tanks.

Tests made with dyes show that there is practically no short-circuiting in the mixing tanks as baffled.

Due to other conditions we have run all the flow through the mixing tanks and sedimentation tanks in series. Attempts will be made in the future to check the operation using one mixing tank and two sedimentation tanks, and for two-stage treatment.

Our tests show that the overall removal of suspended solids is approximately 80 per cent for a sewage with an average strength of approximately 350 p.p.m. suspended solids. This removal varies with the strength of the sewage and with the rate of withdrawal of sludge from the sedimentation tanks. By continuously withdrawing sludge, thereby preventing any accumulation in the sedimentation tanks, it is possible to obtain an effluent of not over 50 p.p.m. suspended solids. However, this requires constant attention so that we have attempted to work out a withdrawal cycle based on the operator's average time. It has been found that thicker sludge is obtained by operating the flight conveyors intermittently, one hour on and one hour off, rather than continuously.

On account of a break in the suction line, Park water was originally used for the water sprays in the sedimentation tanks, but now treated effluent is being used. The spray system works very satisfactorily and moves the scum to the trough at the inlet end to the tanks.

Sludge Control House.—Two sludge thickening tanks, each with a capacity of 17,500 gallons, are located in the sludge control house, the purpose being to obtain a thicker sludge and to observe all operations before pumping to the digester. Ground screenings, grease and sludge fed through sight feeds are added to the thickening tanks.

During the first months of operation, due to certain operating difficulties, it was not possible to get a thick sludge. These conditions have been changed and the average moisture content of the sludge now being pumped to the digester is approximately 95 to 95.5 per cent.

To obtain the most efficient operation it was necessary to make studies of the following problems:

1. Determine whether grease and ground screenings can be added first and then sludge, or whether on top of sludge, by study of surface scum.

2. Make moisture determinations of sludge to determine time concentration to reduce moisture to point desired.

3. Study head losses in discharge pipe by means of pressure and volume readings to determine lowest moisture content sludge that can be pumped with available equipment.

4. Determine effect of chlorine addition on scum and odor.

5. Determine time operation cycle of sludge removal, whether continuous or intermittent, and, if intermittent, time variation with relation to strength of sewage.

6. Determine shut-off elevation in sump through operation of pressure operated mercoid switch.

It was found that a holding time of at least 1.5 hr. is required for the sludge to thicken and that with this holding time approximately 50 per cent of the sludge drawn off from the clarifiers is turned back as supernatant, depending upon the moisture content of the sludge withdrawn. If an attempt was made to so control the draw-off from the sedimentation tanks as to cut down on the amount of sludge, the result would be increased time required for operation and a poorer effluent.

No particular trouble has been experienced with odors in the sludge control house. Chlorine solution is added to the screenings before grinding, thereby eliminating the major portion of the odor from this source. No chlorine solution is added to the surface of the sludge in the sludge thickening tanks.

Chlorination.—Chlorine is added to the sewage before reaching the plant, in proportion to the flow, for odor control and to the effluent leaving the plant, in proportion to the flow, for bacterial disinfection. The operation of the chlorinators and the regulation of the dosage for best results requires supervision and study. In order to get the most efficient operation the following studies have to be made:

a. Determination of hourly, daily, weekly and seasonal variation of strength and flow of sewage to give a pound rate curve. This curve will show the time when adjustment of chlorinator feed is required.

b. Determine p.p.m. dose for odor control as related to total demand.

c. Determine effect on total demand by increasing pre-chlorination dose.

d. Determine percentage variation in grease removal by varying chlorine dose.

e. Determine minimum required chlorine dose for post-chlorination to effect protection of beaches from *B. coli* contamination.

It has not been possible to make all the studies outlined. For pre-chlorination we have found that it is necessary to use a dosage of at least 30 lb. per m.g. to prevent odors. Chlorine for post-chlorination

has been fed at the rate of 60 lb. per m.g. during the period from 8 A.M. to 12 P.M., and 30 lb. per m.g. from 12 P.M. to 8 A.M. It is not always possible to obtain a chlorine residual for the plant effluent as the strength of the sewage varies considerably throughout the day. Further tests are to be made correlating the chlorine demand, chlorine residual and strength of the sewage.

Sludge Digestion.—The digester reduces the organic material which would break down resulting in odors to a point where the sludge can be disposed of without nuisance or odor. This results in the liberation of gas, release of water and reduction in volume and moisture content. It is necessary to so control digestion that the pH of the sludge is about neutral, or above, that the gas will be mainly methane and have practically no hydrogen sulfide.

This requires constant check of pH, gas analysis, composition and moisture content of sludge and constant check of volume and temperature of recirculated water; time regulation of additions and withdrawals to prevent too violent gas formation; and regulation and control of time of operation of motor operated impellers.

The digester was first filled with raw sewage, the temperature increased to 85° F. and the sludge added. Some lime was added with the original sludge. The pH of the digester originally dropped to 6.7 and when no further lime was added dropped to 5.3. As the pH did not increase, lime was added one month after the digester went into operation and the pH raised to 6.7. Since that time the digester has maintained a pH of approximately 6.9 to 7.1 without the addition of any more lime. After about one and one-half months of operation the volatile matter in the digester changed from an incoming sludge of 80 to the digested sludge of approximately 70, showing a reduction in volatile material of 42 per cent. This figure was maintained for about a month, being slightly less at times. After about two and one-half months of operation the reduction in volatile matter increased to approximately 50 per cent and has been between 50 and 55 since that time.

The moisture content of the sludge in the digester at the top and at the bottom varies considerably depending upon a number of factors:

1. The temperature of the digester.
2. The rate of gas production.
3. The amount of withdrawal of digested sludge.

We have not been able to obtain a thick sludge in the digester as yet. This is due partially to the short holding time, the original design calling for two tanks, whereas only one has been constructed. If sufficient sludge is not withdrawn from the digester to the vacuum filter system, the supernatant overflow returning to the plant causes operating difficulties in the sedimentation tanks, increasing the amount of sludge required to be removed in order to maintain an effluent of good quality. We think our troubles in this respect would be eliminated by the addition of the secondary digester.

Studies are being made in an attempt to get thicker sludge based on pumping thicker sludge to the digester, which was not possible before recent changes were made in the Sludge Control House.

Elutriation and Sludge Filtration.—It has been determined that by removing the soluble ammoniacal compounds by washing the amount of conditioning chemicals required for vacuum filtration can be kept at a minimum. Accordingly, the Genter Elutriation System was installed in this plant, the treated effluent being used for the wash water and the dirty water returned to the Sunset Pumping Plant to be recirculated through the system.

For most efficient operation it is necessary to:

1. Determine the relation between wash water and sludge, the speed and time of operation of the mixing units and the time of operation of the flight conveyors.
2. Make constant tests of elutriated material.
3. Determine the strength for most efficient feed of the feeder operated off of the drive of the sludge hoist.
4. Adjust the speed of the bucket elevator by varispeed control to give required amount of feed to the electrically driven sludge mixer and determine proper time of mixing to give most efficient filtration.

The ferric chloride used for conditioning of the sludge comes as a 45 per cent $FeCl_3$ solution. This has to be diluted for daily use to approximately 10 per cent $FeCl_3$.

We have made a number of studies on the proper operation of the elutriation and vacuum filter system. When the sludge was first drawn from the digester and washed it was possible to obtain good filtration using approximately 1.5 per cent ferric chloride based on a sludge of approximately 95 to 96 per cent moisture content. After the system got into regular operation, the amount of ferric chloride required increased to approximately 4 per cent for sludge of approximately 97.5 per cent moisture content, at filtering rates of about 3.5 to 4 lb. per sq. ft. of filter area per hour.

A number of laboratory tests were made based on different quantities of wash water at different times and speeds of mixing. These tests showed that with two washings of approximately 3 to 1 wash water and for mixing just to the point where a heavy floc occurred that it was possible in the laboratory to get results using less than 2 per cent ferric chloride and that as agitation was prolonged the floc was broken up and the time of filtration increased. Accordingly experiments were conducted in the conditioning tank ahead of the vacuum filter for different points of application of the ferric chloride giving different holding times. Based on our work to date it has been found that if the ferric chloride is added to the sludge as it enters the inlet pipe to the vacuum filter without any stirring that best results are obtained and that quantities of chemicals required approximate the laboratory tests. If the sludge becomes thin, that is of a moisture content of more than 97.5 per cent, the ferric chloride requirements increase. Further tests are

to be conducted to substantiate these conclusions and for improvement of operating conditions.

Sunset Pumping Station.—As stated, the flow from the Mile Rock sewer from the Sunset District is diverted by a movable dam operated by an automatic gate raising device in the Mile Rock sewer to the Sunset sump. In the design of the plant provision was made for a scraper in the sump to scrape the sand to a pit and for a pump to pump the sand to a sand washer discharging onto a belt conveyor to a hopper. This installation was made with full knowledge that it might not be adequate to handle the sand and that additions and changes might have to be made if required.

The quantity of sand brought in by the Sunset sewage was so great, at times approximately 10 cu. yd. per day, that the existing equipment did not function properly. Accordingly a new layout has been made which embodies provision for carrying the sand to a trough, agitation of the sand in the sump, and a pump to maintain velocities of at least 8 ft. per second, which installation has not been made as yet. Until this installation is made, sand will continue to accumulate in the sump and have to be pumped periodically to the sewer.

Conclusions

Although there are a number of problems yet to be solved, we feel that the operation to date has been satisfactory and is substantially in accordance with the proposed design.

II. LABORATORY CONTROL OF THE OPERATION OF THE RICHMOND–SUNSET SEWAGE TREATMENTT PLANT

By K. Fraschina

Asst. Supt. and Technician

The purpose of the laboratory is three-fold:

1. To obtain data on plant operation for record and control.
2. To attempt to improve the operation of each unit for maximum efficiency.
3. To do such research work as is necessary for information on the design of future additions to the plant and for any new plants that may be constructed.

Daily tests are made of the strength of the raw sewage and plant effluent in suspended solids, per cent moisture and volatile matter of sludge pumped to the digester, pH, per cent moisture and volatile matter of sludge at the top and bottom of the digester, strength of ferric chloride used as a sludge conditioner, and per cent moisture and volatile matter of the elutriated and filtered sludge. In addition, analyses are

made periodically of the sludge gas, of the chlorine demands and residuals, of grease content, and B.O.D. of the raw and final effluent.

These tests serve as indicators of plant operation and the operation is adjusted in accordance with the results obtained. A higher effluent indicates that supernatant is coming over from the digester or that sufficient sludge is not being drawn from the sedimentation tanks.

Moisture content of the thickened sludge indicates whether the settling period is sufficient or whether enough supernatant is being returned to the system.

The tests for the digester indicate whether this unit should be rested or not and whether sludge should be withdrawn.

Tests of the elutriated and filtered sludge and the quantity of ferric chloride used give data on the results and efficiency of these processes.

Considerable work has been done towards finding a simple method for the determination of suspended solids and the Chicago Sanitary District method using a Buchner funnel and filter paper has been decided on as being the most satisfactory for our purpose.

Our tests have shown that this method is simpler and gives much more reproducible results than the Gooch crucible method. Our tests have also shown that 24-hour composite samples for suspended solids on either the raw sewage or plant effluent give very erratic results, the suspended solids increasing for the first two or three hours and then decreasing thereafter. The present procedure is to run the suspended solids on the raw sewage and plant effluent at 8-hour intervals during the day, changing the time each week so that an average curve can be drawn for a month for both the raw sewage and plant effluent. From this curve we can go back and compute the weighted average suspended solids for each day using the individual suspended solid values and the flows at the time. In this way it is possible to get a closer approximation to the actual suspended solids in the sewage than can be obtained with a 24-hour composite sample.

It is difficult to get representative samples of the effluent from the grit-grease tanks and we have not been able to determine as yet the efficiency of the grease removal of the tank as a unit but must report the grease removal as a whole, as Mr. Benas has previously stated.

In addition, laboratory work is being done with several methods of grease determination using various solvents to determine which method gives the best results.

Considerable work has been done in an attempt to correlate the chlorine demand of the plant effluent as determined in the laboratory with actual residuals obtained in plant operation.

Rather extensive elutriation tests have been run in the laboratory using various wash water ratios on digested sludge and plant elutriated sludge to determine the optimum ferric chloride dosage and the best mixing conditions, based on the time of vacuum break. The tests indicated that we could satisfactorily filter sludge using less ferric chloride than was being used on the vacuum filter. Accordingly experiments were conducted with various mixing conditions in the conditioner

of the vacuum filter and results have been obtained comparable with the laboratory findings. Computations on sludge solids and water filtered in the vacuum filter indicated that the vacuum filter can only do so much work in removing water from the sludge. Based on these results changes were made in the piping of the vacuum filter system which improved the operation.

Daily laboratory results are recorded on tabular forms so designed that the changes and operations of the plant can be detected easily. These records are not only useful for the control of the operation of the plant but also serve as a permanent record for future reference.

Simple tests have been devised wherever possible to assist the operators in the operation of various processes. For instance, the control of ferric chloride feed for conditioning of the sludge to the vacuum filter is by a vacuum break test which is made by the filter operator.

The laboratory results obtained are limited by the extent to which the samples are representative. A special effort has been made to devise sampling schedules so that the best representative samples are obtained without undue interference with other plant duties of the attendants.

A brief description of some of the laboratory work has been given. In conclusion it must be emphasized that without definite knowledge of what is taking place it is impossible to get the most out of a plant.

III. MAINTENANCE AND OPERATION OF THE RICHMOND–SUNSET SEWAGE TREATMENT PLANT

By Ralph R. Sotter

Chief Operating Engineer

The operating personnel consists of five stationary steam engineers who serve as shift operators and do maintenance work; four sewage pumping station attendants who serve under the operators on shift and assist in maintenance; two laborers and one truck driver.

We were particularly fortunate in obtaining men for the above classifications who have considerable skill and were able to adapt themselves to the operation of the equipment and processes and do maintenance and repair work. In determining an operation schedule an attempt has been made to rotate the men so that all would become acquainted with all of the equipment and processes.

The operating schedule is laid out so that a shift operator and attendant are on duty three shifts a day, that a vacuum filter operator, who is a stationary steam engineer, is on duty from Monday through Saturday, and that a maintenance man, who is a sationary steam engineer, and an assistant, who is a sewage pumping station attendant, are on duty from Tuesday through Thursday. The laborers and truck driver work from Monday through Friday.

In order to obtain operating data, log schedules of operation have been set up and daily record forms are kept. Some changes had to be made from the original and we will shortly have complete forms for all of the plant. These cover the operation of the Pre-Treatment Building, Mixing and Sedimentation Building, Main Building and Digester, and are made out by the attendant or the operator on shift.

For the Pre-Treatment Building, information is recorded as to the bar rack operation, amount and time of screenings haulage, rate of pre- and post-chlorination feed, blower operation, and general remarks.

For the Sludge Control House and Mixing and Sedimentation Building, information is recorded on shredder operation, sludge pump operation, time of withdrawal from the sedimentation tanks, quantity of sludge pumped to the digester and supernatant return to the system, operation of the mixing and sedimentation tanks and general remarks.

For the Main Building, information is recorded on the operation of the sewage pumps, the elutriation system, vacuum filter system, boiler room and sludge and sand haulage.

For the Digester, information is recorded as to the temperature, amount and temperature of recirculating water, sludge pumped to and withdrawn from, and quantities of gas to the boiler and waste gas burner.

We have attempted in the first months of operation not only to keep the plant running but to try out the equipment under limiting conditions to determine any defects as the contractor has put up an equipment bond for one year. A number of defects have been found which were repaired or replaced by the manufacturers.

Particular attention has been paid to lubrication and packing. The manufacturers have been consulted, and in most cases their recommendations followed. Charts have been made showing when each piece of equipment should be lubricated and the kind of lubrication to be used.

Pumps and all mechanical equipment are given periodic inspections dependent upon their service.

A special problem has presented itself in the operation of the electrical motors, especially in the Pre-Treatment and Mixing and Sedimentation Buildings. Due to damp conditions and the intermittent operation, some of the motors developed heavy grounds. These motors were removed, the stators baked for 48 hours and dipped in hot insulating varnish. So far the motors have tested out clear.

In the design of the plant electric controls were furnished at various locations and alarms indicating limiting conditions. These have proven very satisfactory and have been of great assistance.

The location of the plant just off of the ocean is conducive of corrosive atmospheric conditions which affect metal so that it is necessary to do considerable painting. The life of the paint coat is dependent upon the method of application, and it is necessary to see that the metal is clean before applying the paint. Proper ventilation, which

helps to keep the amosphere dry, has been a great aid in preventing corrosion in a number of locations.

The gas obtained from the digester has been used in the boilers after the carbon dioxide content became less than 35 per cent. This gas burns with a clear flame with practically no soot. Some trouble was experienced with the operation of the gas meters due to accumulation of water, the meters serving as traps, which trouble has been eliminated by installing special traps and connections for draining.

Special attention is given in handling sludge in pipe lines, frequent tests being made to see that the lines are clear by flushing.

Another part of the plant is the machine shop. A vise, cutting and welding outfit, drill press, grinder, dies and other tools have been provided to make repairs. These have been a great aid in keeping the plant in operation and preventing delays.

In addition to normal stocks, we are endeavoring to build up a supply of repair parts which are considered essential, especially for that equipment for which it is not possible to obtain parts locally. A number of delays would have been prevented if such a stock were on hand.

In closing, I want to stress four considerations for which we are particularly fortunate:

1. The fact that we have first class standard equipment of responsible manufacturers with available service.
2. A layout of plant and equipment which provides for ample working space for removal, repairs, adjustments and changes.
3. Adequate provision for water at convenient locations.
4. Adequate lighting.

Industrial Wastes

EFFECT OF CANNERY WASTES ON OPERATION OF SEWAGE TREATMENT PLANTS *

By William A. Ryan

Sanitary Chemist, Rochester, N. Y.

The term "Cannery Waste" is a composite term inasmuch as it includes the waste liquors from such a variety of fruits and vegetables. Canning plants require large quantities of water as all soil, vegetable tissue, skins, pulp and other organic matter must be washed out of the edible portion which is canned.

From the chemical point of view, the main problem in treating vegetable waste is one of breaking down by oxidation the high content of sugars and starch to water and carbon dioxide, and screening out the cellulose. The vegetable acids as well as the fruit acids can easily be neutralized. Chemical treatment or Bio-Flocculation ahead of settling tanks is helpful.

The following figures were obtained from Mr. Lee Taylor, Secretary of the Association of New York State Canners Inc., and they will show the importance of the canning plants to the industrial life of New York State:

> The New York State canning plants number more than one hundred. Confining our figures strictly to the regular lines of canned vegetables and fruits packed during 1937 such as peas, beans, corn, tomatoes, beets, carrots, potatoes, cucumbers, spinach, pumpkin, squash and cabbage and omitting chili sauce, catsup, soups, fruit juices, pork and beans, spaghetti, jams, jellies and preserves, there were packed 14,185,580 cases of number twos or 340,453,920 cans in all. The combined pack had a sales value of $35,590,000. That year the canners paid the growers $9,879,393 for the raw products. The growers had more than 112,000 acres under cultivation for vegetables alone under contract with the canners.
>
> The canners throughout the state gainfully employed during the 1937 season about 8,000 workers whose wages totaled $5,585,293. The cities, towns, and villages receive in real estate taxes alone nearly $250,000 from the canners.

The figures above refer to cans and when one adds the fruits and vegetables packed in glass plus the frozen foods, the figures become much larger. The variety of pack numbers seventy-three. Tomatoes for example are packed in the form of tomato juice, catsup, canned tomatoes, chili sauce, paste, soup and pulp.

The figures on acreage devoted to apples, cherries, grapes, pears, peaches, plums and berries sold to the canners are not available.

The canning season for standard line vegetables and fruits starts on June 1st and lasts until December 1st. There are a few plants which operate the full 12 months. Assuming that each case of cans required

* Presented at the Fall Meeting of the New York State Sewage Works Association, Olean, October 7, 1939.

20 gallons of water for washing the raw materials the total waste will be approximately 14,185,580 × 20 or 283,711,600 gallons of waste and an equal volume of cooling tank water.

From the figures and data given above, the canning business is seasonal and the waste will likewise be variable in volume and organic content. The following table compiled from analyses of wastes received at our laboratory and analyzed by Mr. Valerio and the author will give some idea of the strength of various wastes. These figures are average and they vary over a wide range.

TABLE I.—*Analyses of Various Wastes*

Results in Parts per Million

Raw Waste	B.O.D. 24 hrs.	B.O.D. 120 hrs.	Settleable Solids	Suspended Solids	Ash	Total Solids	Ash	pH	Oxygen Cons.
Tomato	415	1,150	100 c.c./liter	450	80	2,500	580	4.9	1,100
Pea	1,080	2,710	—	300	25	6,000	3,360	4.7	2,150
Pea ensilage	—	35,000	—	—	—	87,000	13,000	4.1	28,000
Corn	250	2,500	—	1,420	110	5,170	415	5.6	4,325
Corn ensilage	—	27,000	—	—	—	46,700	13,200	4.5	15,000
Lima bean ensilage	—	25,000	—	—	—	47,250	12,200	5.2	13,000
Wax Beans	70	240	4	60	10	1,675	970	7.6	—
Spinach	80	280	—	580	150	1,700	950	7.0	40
Carrots	—	1,110	60	1,830	170	5,800	1,900	7.1	—
Beets	400	1,500	35	1,600	220	5,000	800	6.0	2,700
Saurkraut	—	1,400	4	60	5	3,300	1,600	5.6	800
Cherry	390	750	—	20	4	4,100	1,700	6.2	—
Grape	—	720	25	1,650	—	2,600	880	4.6	—
Potato	50	220	—	990	400	1,600	700	7.3	—
Pickle	170	3,000	—	200	70	4,000	12,000	4.0	2,800

Discussing these figures, one can pick out the big four from the list, namely corn, pea, tomato, and beet waste.

Corn is by far the worst waste encountered. It does not readily respond to chemical treatment or to plain sedimentation, the carbohydrates are present in the form of starch, the suspended matter is held in colloidal suspension, and the B.O.D. extends over a long period of time. Corn is packed during August and September. A typical corn waste collected after passing through a 40-mesh screen analyses is shown in Table II.

Pea-canning waste is highly putrescible and the carbohydrates are present for the most part in the form of quickly reducible sugars. Peas are packed during June and July. Table III shows the analysis of an unusual pea waste collected at a plant where the waste is heavy and the water conserved.

Tomato waste is a problem because of the heavy tonnage packed and the large volume of water used. Tomato waste contains a high percentage of suspended matter which can be screened out before treatment. Tomato season usually starts on August 20th and extends

TABLE II.—*Analyses of Corn Packing Wastes*

Results in Parts per Million		
Suspended solids	1700	
Loss on ignition (organic)	1666	
Fixed residue (inorganic)	34	
Settleable solids	20	c.c./liter
pH value	3.7	
Total solids	4713	
Loss on ignition	4403	
Fixed residue	310	
Dissolved solids	3013	
Loss on ignition	2737	
Fixed residue	276	
Dissolved oxygen	0.0	
Bio-chemical oxygen demand		
24 hours	500	
120 hours	2300	

TABLE III.—*Analyses of Pea Canning Wastes*

Results in Parts per Million	
B.O.D. 24 hours	4,200
B.O.D. 120 hours	7,800
pH value	4.4
Chlorides	400
Suspended solids	2,696
Loss on ignition	2,408
Fixed residue	288
Dissolved solids	16,070
Loss on ignition	13,960
Fixed residue	2,110

to October 5th. At one plant, near Rochester, it is not unusual to wash and process 1,000 tons per day during the first three weeks of September.

Beet waste is troublesome because of the tops, tails, skins and color of the waste. The sugars in the beet waste are likewise high in B.O.D. Carrot waste is somewhat similar to beet waste.

Berries and fruits, with the exception of apples, are not troublesome nor difficult to treat.

Kraut and pickle wastes are low in volume but high in acids and odor producing compounds.

Ensilage (silo) waste from pea vines, corn husks, corn cobs and lima bean vines is not a plant waste but produced from fermentation of the sap in the vine, pods or husks. These wastes should never be taken into a sewage treatment plant under any circumstances. The best method of disposal is by means of irrigation upon land.

There are two agencies in the State, namely the State Department of Health and State Conservation Department, which are vitally interested in waste treatment, the State Health Department from the standpoint of health and nuisance and the Conservation Department from the standpoint of the effect of waste on fish life in the stream. In addi-

tion, the local health departments and local chapters of the Isaak Walton League keep a watchful eye on the canner.

We have now reached the point in our discussion where the sanitary engineer comes into the picture.

Many canning plants are located in a small town or village where there is no sewage treatment plant and the nearby creek has a habit of going dry or nearly so during the height of the canning season. The fortunate canner who has located in a city or village which has a sewage treatment plant can seek assistance from the municipality to the extent of emptying the screened waste into the sewer.

Canning waste (if not excessive in volume) can be discharged into the sanitary sewer and treated. Preliminary treatment at the cannery to the extent of passing the waste through a 40-mesh screen and adjusting the pH is essential.

Every cannery waste must be studied separately as it is seldom that any two plants have the same canning schedule. It is unusual to have tomato and corn waste from the same plant. Corn and tomatoes mature at about the same time and it requires too much floor space to set up for both packs.

There is lack of consistency or uniformity among engineers in the unit selected for basing the expected volume of waste. One may report the volume of waste based on cases of No. 2 cans packed, another on number of lines in service while still another will calculate on bushels or tons or raw vegetable processed.

There are two distinct wastes discharged from a cannery. The cooling tank water may be discharged to the storm sewer or stream. This represents approximately one-half of the water used. The waste proper consists of wash water used in cleaning the raw product, the blancher water in the case of peas or the second wash water in the case of whole kernel corn and tomatoes and the cleanup water from the cleaning of picking tables, walls, floors, benches, etc.

The average cannery operates 10 to 14 hours per day, but it is desirable to have the waste reach the sewage treatment plant uniformly during the 24 hours. This fact should not be overlooked by the sanitary engineer and collection tanks may need to be considered for 24-hour flow to the sewage treatment plant. There is need for better metering of water and waste at the average canning plant.

Figured on a wet basis, a well constructed and installed 40 mesh screen will remove from 30 to 35 per cent of the suspended solids in the case of tomato waste and 5 to 12 per cent in the case of other wastes. Taking tomatoes again as an example and assuming 39 gallons of waste per bushel of average weight of 83 lb. we have 24 bushels to the ton and 936 gallons of waste to treat. Assuming 450 p.p.m. suspended solids passing the screens we have $450 \times .0083 \times 0.936 = 3.5$ pounds of suspended solids and $1540 \times 0.0083 \times 0.936 = 12.0$ pounds of soluble organic matter or 15.5 pounds (dry basis) in all to remove as sludge or to reduce by oxidation, per ton of tomatoes. A 100-ton pack will give the treatment plant 1,550 lb. of soluble and insoluble waste and 93,600

gallons of water. Other wastes may be calculated in the same manner. It is approximately correct to assume that a 40-mesh rotary screen will remove 75 cu. ft. of wet screenings per 100,000 gallons of tomato waste. This can best be removed at the canning plant rather than at the sewage plant.

Mohlman suggests that a sewage treatment plant may be able to handle organic waste if the population equivalent of the waste does not exceed the human population tributary to the treatment plant.

Dividing the B.O.D. of 2,710 by 200 in the case of pea waste it is found that one part of pea waste may be handled successfully with 13.5 parts of sanitary sewage while in the case of tomato waste one part of waste may be handled with six parts of sanitary sewage. This may hold true if the treatment plant provides for primary and secondary treatment and the receiving stream has sufficient water for proper dilution.

In the case of the above assumption, the B.O.D. of the incoming mixture of waste and sewage has risen from 200 to 380 p.p.m.

An Imhoff tank installation or settling tank and separate sludge digestor should handle the load during the warm months of the year provided the sludge is digesting normally.

Trickling filters will handle this extra load provided suspended solids are removed in the tank ahead of the filter.

Fill-and-draw tanks ahead of the regular tanks where chemicals (iron or aluminum salts plus lime) can be added and the mixture agitated and allowed to settle after which the sludge can be removed and dried without digestion should handle a much heavier ratio of waste to sewage. The clarified waste-sewage mixture can then pass through the regular units of the treatment plant.

Bio-flocculation without chemical addition and recirculation of the clarified mixture on a properly functioning trickling filter will work with skilled operation.

The addition of chemicals to the Imhoff or settling tank has been suggested. Such a plan is being used at the Dearborn, Michigan, plant. The writer has not had a similar experience.

Canning waste from two large plants, waste from three breweries, ammonia-still waste and other organic wastes enter the Main Sewage Plant at Rochester, N. Y. The ratio of waste to sewage is not more than 1 to 20 at any time and no trouble is experienced. The heaviest waste load comes during the tomato season when the screenings from the Reinsch Wurl screens go as high as 30 tons per day with a peak of 54 tons during one day of September, 1938.

The normal digesting pH value of the sludge is 6.5 with no foaming. The scum or top sludge is above normal due to tomato skins passing the ⅛ inch slot in the Reinsch Wurl screen plates. Approximately 1,500 cu. yards of scum from the gas slots of the 20 Imhoff tanks have been removed this year by means of a crane and a ⅓ cu. yd. bucket.

This plant has no secondary treatment and the B.O.D. removal is low. The suspended solids of the incoming sewage is increased from

170 p.p.m. normal to 200 p.p.m. during the tomato season with a marked percentage increase of removal through the tanks due to the coagulating effect of the tomato pulp on the sewage solids. No chemicals are added to the Imhoff tanks and only a small amount of bleaching powder added to the screenings. The sludge digests well and dries well on the sand beds. Holley, Fredonia, Oakfield, Geneva and Albion sewage plants treat cannery wastes in season with success.

The Oakfield plant is not able to handle the peak load as the waste is greater at times than the sewage flow. Westfield has a plant under construction to treat sewage and wastes.

From the writer's experience in treating cannery waste at the canning plant or in sewage treatment plants, the following observations have been noted:

1. Treat the waste as soon as possible.
2. The wastes respond to chemical treatment when fresh but not so well when septic.
3. Activated carbon is useful in reducing odors in waste solids and ensilage juice.
4. Bleaching powder is useful on screenings dumps and trickling filters.
5. A shaker type 60-mesh Link Belt screen has worked well at one large canning plant.
6. An excellent spirit of cooperation exists among the canners of New York State to assist the State in cleaning up unsatisfactory stream conditions.
7. No municipality in New York States levies any extra tax on any canner for treating the waste at existing sewage treatment plants.

General Conclusions

1. Canning waste (if not excessive in volume) should be treated in existing sewage treatment plants.
2. It is not economical to employ a screen at a sewage treatment plant with less than 16-mesh or, better, 8-mesh.
3. Preliminary treatment by the industry is essential in most cases.
4. There is greater danger to public health from untreated sewage than untreated cannery waste.
5. Activated sludge type plants do not appear to be suitable for handling cannery waste as bulking is increased due to the increase in *Sphaerotilus* growth from increase in carbohydrate content in the waste-sewage mixture.
6. Removal of all possible solids within the canning plant as garbage rather than as liquid waste reduces the load on the treatment plant.

Summary

The whole canning waste problem to date may be summarized by using a quotation from the late Cecil Rhodes "So much to do. So little done."

The canning industry is growing and welcomes any constructive suggestions from sanitary engineers in solving their waste problems.

Acknowledgments.—The writer gratefully acknowledges the assistance of Paul Valerio and Lee Taylor for their valued contributions.

DISCUSSION OF MR. W. A. RYAN'S PAPER ON CANNING WASTES

By C. J. Bernhardt

District Sanitary Engineer, N. Y. State Department of Health, Jamestown, N. Y.

Experiences with the handling of canning wastes at the sewage treatment plants serving several of the smaller municipalities in Western New York are considerably unlike the problem at Rochester just related by Mr. Ryan, where the ratio of canning wastes to total sewage flow is 1:20. It is true that in the smaller municipalities, where the preserving and canning of fruits and vegetables comprise the principal industry, the ratio of canning wastes to total sewage flow may be considerably greater, such as 1:2 or 2:3.

A typical community of this nature is Fredonia, New York, where the volume of industrial wastes derived from the canning industry alone is much greater at times than the average sewage flow. During the canning season the sewage treatment plant serving this village is called upon to treat, along with the normal domestic sewage load, a volume of industrial wastes from the seven canning plants in the village.

The normal domestic sewage load from the 5,500 population averages about 300,000 gallons per day. Treatment provided at the plant consists of a hand raked bar screen grit chamber, and Imhoff tanks for primary treatment with secondary treatment of trickling filters, chlorination and second settling tank. The watercourse, into which the sewage is discharged, is Canadaway Creek, flashy in character, and in times of dry weather has an estimated flow of from 1.0 to 1.5 M.G.D.

However, with the addition of industrial wastes during the canning season, the plant is called upon to treat a total of an additional 300,000 to 600,000 gallons of wastes, beginning in July until the end of October. The population equivalent for the industrial waste load varies from 1,500 to 7,500 expressed on a B.O.D. basis.

When the sewage treatment plant was first placed in operation in 1927, the discharge of various raw canning wastes taxed the plant to capacity and it was not possible to treat the sewage sufficiently to prevent nuisance conditions in the receiving water course. At that time the problem was presented to the various industries and cooperation by all industries was assured.

In 1929, the village enacted an ordinance requiring the pre-treatment of all wastes, with the exception of domestic sewage, before discharge into the sanitary sewer system. The requirements of treatment at the source were that all parties depositing trade wastes were required to provide and maintain screens of sufficient fineness to remove all solids.

Without such a pre-treatment device, the offender would be charged with a misdemeanor and fined $50 for each and every day the violation occurred. Fortunately, the village has not seen fit to impose this penalty. A screen of sufficient fineness was considered to be one with 20 meshes or more to the inch. With such an ordinance in force, the operation of the sewage treatment plant was facilitated considerably.

The receipt, this summer, of several complaints regarding the existence of nuisance conditions in the 4-mile stretch of Canadaway Creek before it enters Lake Erie, brought about an investigation of the sewage treatment plant. This occurred during an extremely dry season when the flow in the creek was at a minimum, and, incidentally, was during the tomato canning period. The bar screen, where the sewage enters the plant, was given practically constant attention and a considerable volume of tomato pulp, skins and even whole tomatoes was being removed daily. The unusual character of the wastes led to an investigation of the five industries processing tomatoes.

At one tomato canning plant a break in the revolving screen several inches in length allowed a considerable volume of tomatoes, skins, seeds, and pulp to enter the sanitary sewer which by means of a tight screen would be eliminated.

At a second canning plant, the 20-mesh screen was broken and replaced with a coarser one of 6 mesh. Here a high percentage of tomato seeds and pulp passed through it into the sanitary sewer system, which would ordinarily be eliminated.

The problem was different in the third plant. The rinse water used to keep the screen clean was not at sufficient pressure to rinse the screen thoroughly with the result that the screen was constantly clogged and the material held by the screen was overflowing through the inlet and found its way to the sanitary sewer system. By a re-arrangement of piping and installing a 1¼ in. pipe in place of the original ½ in. pipe, the pressure was increased to 50 lb. and the screen was effectively cleaned.

The remaining two canning plants had satisfactory screens in proper operation.

It is interesting to note the effects of canning wastes on the operation of the sewage treatment plant. Naturally the sewage arriving at the plant is different in character. This may be summarized as follows:

	Domestic Sewage Alone	Domestic Sewage and Industrial Wastes
Screenings removed per day (cu. ft.)	3	8 to 10
Settleable solids raw, c.c.(litre)	4 to 12	18 to 40
Chl. demand, effluent (p.p.m.)	4.5 to 6.2	15 to 32

During the canning season, there is a tendency for the gas vents to accumulate scum rapidly and foam. Lime is applied from two to three times a week in 100 lb. doses to the gas vents and thoroughly hosed down. Prechlorination is practical from July 1 to October 31 at a rate of about 20 lb. per 24 hrs. This has a tendency to reduce odors about

the plant and to assist in sedimentation. Occasionally a few of the trickling filter nozzles will become clogged with fruit or vegetable solids, mostly skins which do not decompose readily.

Notwithstanding the burden which is placed on this plant, it is only on rare occasions, in the absence of sufficient diluting water in Canadaway Creek, that objectionable conditions occur.

Going back to the individual pre-treatment devices at the canning plants, which in each instance consisted of a revolving cylindrical screen, it is difficult to realize how such a simple mechanism can cause so much trouble. Experience has shown that a fine bronze screen, if properly designed, installed and maintained, will render years of service without replacement.

The size of the screen should be governed by the volume and character of the wastes to be treated. Precaution should be taken to prevent objects entering the screen which would have a tendency to rupture it. At one plant a broken screen was observed which was ruptured by a piece of 4 in. angle iron that was carelessly allowed to enter. Occasionally the man at the plant will take a sharp pointed shovel in an effort to scoop out material adhering to the inside of the screen. This practice naturally shortens its life.

Water or steam jets of sufficient pressure should be available for the continuous rinsing of the screen. By improper rinsing, the screen will be subjected to abnormal stresses that have a tendency to rupture it.

As the superintendent of a canning plant is interested principally in the processing of foods, he is likely to give little attention to the effectiveness of his waste treatment unit or plant. On the other hand, the sewage plant operator is interested in the proper treatment of sewage at his sewage treatment plant and when canning wastes are present is called upon occasionally to do the impossible. Therefore, it is my belief that every sewage plant superintendent who has to deal with canning wastes should have a definite knowledge as to the volume and character of the various wastes received at his plant. He should visit the industries frequently in his community to determine whether or not the pre-treatment devices are operating in an effective manner. In practicaly every instance, he will find that the industry is only too willing to cooperate. Perhaps an ordinance such as has been established at Fredonia will be the answer. It is only by mutual cooperation between the municipal authorities and the industries that difficulties at a sewage treatment plant can be kept at a minimum.

THE TREATMENT OF DAIRY WASTES*

A REPORT ON THE OPERATIONS OF AN ACTIVATED SLUDGE TREATMENT PLANT FOR DISPOSAL OF DAIRY WASTES AT THE H. W. WALKER COMPANY, SOMERSET, PENNSYLVANIA

By Sylvan D. Montagna

Assistant Engineer, Commonwealth of Pennsylvania, Department of Health, Bureau of Sanitary Engineering

The dairy wastes from the H. W. Walker Company of Somerset, Pennsylvania, producers of bottled milk and cream, whole and skimmed milk, cultured buttermilk, butter, ice cream, ice cream mix, bulk cream, skimmed condensed milk, powdered skim milk and cottage cheese, have been successfully treated by the activated sludge process. At present, there are two such treatment plants operating in the United States, for the disposal of practically the same type of dairy wastes. The other plant is at the White Mountain Creamery Company located in New Bremen, Ohio.

The activated sludge idea in waste treatment is not new, as it has been used extensively with other wastes. However, milk product factory wastes are difficult to attack since their concentrations are so variable and their pollution load so great; and, in a dairy manufacturing so many different milk products, the wastes are extremely high in total solids and oxygen demanding substances.

The H. W. Walker Company receives an average of 60,000 pounds of fluid milk daily, of which approximately 90 per cent is processed into dairy products, 8 per cent is bottled, and the remaining 2 per cent represents the milk loss. The volume of waste from all processes, including can and bottle washings, equipment and floor washings, is 50,000 gallons daily.

Equipment and Operating Procedure.—The essential units of this activated sludge treatment plant are a lime tank, the receiving chamber or wet well, mixing chamber, primary settling basin, aeration and final settling basins. Two conventional-type air blowers and air-lift devices. The mixing chamber and aeration basin are equipped with concrete diffuser plates on the bottoms to diffuse the air from the blower. One of the air blowers is merely an auxiliary unit, connected to the system by an automatically controlled switchboard, for use in case of emergency or breakdown, since the system must be operated continuously to avoid septic conditions.

The mixing chamber and all basins are constructed of concrete. The total capacity of the entire system is 86,400 gallons, equivalent to a 36 hour retention period based on the average daily flow of 50,000 gallons.

* Presented at the Thirteenth Annual Conference of the Pennsylvania Sewage Works Association, State College, June 27, 1939.

The raw waste flows by gravity to the deep receiving chamber, or wet well, of 2,400 gallons capacity. The dimensions of this tank are 4 by 6 ft. by 13½ ft. deep. An air-lift device raises the raw waste into the mixing chamber, where it is mixed with milk of lime from the lime tank to maintain a pH range between 8 and 9 (approximately 100 p.p.m.). The lime solution serves to neutralize the lactic acid and precipitate the suspended caseins in the raw waste to form a sludge, and to prevent septic conditions in the primary settling basin.

The mixing chamber is a 10 ft. square, hopper-type basin with perpendicular sides down to a depth of 4 ft. and thereafter with 60° slopes from the horizontal. The maximum depth of this chamber is 11 ft. The mixture is constantly agitated by a current of air diffused through a concrete diffusion plate 2 ft. square, while the sloping sides prevent the accumulation of undesirable and decomposable matter within the chamber. The capacity of this chamber is 6,000 gallons.

From the mixing chamber the effluent passes over a weir into the primary settling basin, which is approximately the same size and shape as the mixing chamber. An air-lift device returns part of the settled sludge from the bottom of this basin to the mixing chamber for recirculation. The primary basin is also provided with a by-pass line to convey the settled sludge to a tank truck to be hauled to an adjacent field. Three hours before the removal of the sludge, the recirculation air lift is turned off to allow the sludge to settle. The amount of sludge removed once daily from this basin is 400 to 500 gallons, containing approximately 50 per cent settleable solids by volume.

The effluent from the primary settling basin flows over a weir to the aeration basin, which has a capacity of 60,000 gallons. The aeration basin is a rectangular, dual hopper tank with a surface area of 66 by 20 ft. The perpendicular sides of the perimeter descend to a depth of 1 ft., with 60° slope from the horizontal below the perpendicular sides. The base of each rectangular hopper has a horizontal channel 14 in. wide and 54 ft. long. The maximum depth of this basin is 9½ ft. Each horizontal channel is provided with 10 concrete diffusion plates, 1 ft. by 4 ft., which are connected to the air blower. The retention and aeration period in this basin is about 24 hours.

The lactic acid-forming bacteria in the aeration basin convert the milk sugars to lactic acid, thereby reducing the pH to between 7.6 and 7.8, the most favorable reaction for this type of bacteria. A further decomposition of the milk sugars occurs simultaneously to form carbon dioxide and water. Sufficient aeration is maintained to keep the dissolved oxygen above 2 parts per million.

The overflow from the aeration basin passes over a weir into the dual hopper-final settling basin of 12,000 gallons capacity. The shape of each basin-hopper is the same as that of the mixing chamber. The dimensions of this tank are 20 by 10 ft. with a maximum depth of 13 ft. Air lifts returned the settled sludge from the bottom of each hopper to the aeration tank for recirculation and seeding.

The clear effluent from the top of the final settling basin is drawn off by three overflow troughs and passes into a small stream.

Cost of Construction and Operation.—The entire cost of installation of equipment and construction of all basins was estimated at $12,000. The costs of operation per day include 50 lbs. hydrated lime, power for 5 H.P. motor operating the air blower continuously, 2 hours of labor time, and the expense of operating an antiquated tank truck.

Calculations based on the capacity of the air blower, operated by a 5 H.P. motor, 860 R.P.M., show that the quantity of air used for all purposes; namely, mixing, aerating, and operating air lifts, is 2.8 cu. ft. per gal. of waste. (Capacity of blower—96 cu. ft. per minute.)

The amount of B.O.D. removed daily by 115 K.W.H., the power consumed, is 224 pounds, or .51 K.W.H. per pound of B.O.D. removed.

During the three-year period that this plant has been operating, the entire system was cleaned only two times.

Results

The results in Table I are based upon a study made at this plant by the Pennsylvania Department of Health, periodically over a three-year period. Table II is a tabulation of data collected at the White Mountain Creamery Company, New Bremen, Ohio, during a period of 83 days. This plant is operated by the American Solvent Recovery Corporation of Columbus, Ohio.

Table I.—*H. W. Walker Company, Somerset, Penna.—Operation of Activated Sludge Treatment Plant*

	Volume, Gallons	Raw Waste			Effluent			B.O.D. Reduction, Per cent
		pH	5 day B.O.D., P.p.m.	Total Solids, P.p.m.	pH	5 day B.O.D., P.p.m.	Total Solids, P.p.m.	
Average.....	50,000	7.2	545	797	7.7	7.4	466	98.4
Maximum....	70,000	8.2	1,800	1,030	8.1	16.5	660	
Minimum....	30,000	5.2	260	660	7.3	1.7	316	

Table II.—*White Mountain Creamery Company, New Bremen, Ohio—Operation of Activated Sludge Treatment Plant*

	Volume, Gallons	Raw Waste			Effluent			B.O.D. Reduction, Per cent
		pH	5 day B.O.D., P.p.m.	Total Solids, P.p.m.	pH	5 day B.O.D., P.p.m.	Total Solids, P.p.m.	
Average.....	34,100	7.5	1,285	6,465	—	4.8	—	99.7
Maximum....	51,000	9.5	1,625	7,825	—	10.6	—	
Minimum....	17,100	5.0	413	5,105	—	0	—	

The high reduction in B.O.D. values obtained at both plants, as shown in Tables I and II, attests the success of dairy wastes disposal by the activated sludge process. The reduction in population equivalent accomplished is from 1,400 to 18 people.

Summary and Conclusion

The activated sludge process has been successfully used for the disposal of milk product factory wastes. The major conditions necessary for successful operation are:

1. Sufficient milk of lime must be used to precipitate and neutralize the suspended caseins and lactic acid in the raw waste, to prevent septic action in the primary settling basin, and to maintain a pH of 7.6 to 7.8 in the aeration basin.
2. The sludge in the primary settling basin must be recirculated with fresh waste in the mixing chamber to produce a more readily settleable sludge in the primary settling basin.
3. Before the sludge is removed from the primary settling basin to the tank truck, recirculation to the mixing basin is stopped to allow sufficient time for settling. At the Somerset plant, three hours has been found to be sufficient time for settling.
4. Sufficient aeration must be provided to continuously agitate the mixtures in the mixing chamber.
5. Sufficient aeration must be maintained in the aeration basin to keep the dissolved oxygen above 2 parts per million to avoid septic conditions.
6. The sludge in the final settling basin must be recirculated to the aeration basin for the purpose of seeding the effluent from the primary settling basin.
7. Auxiliary blowers must be provided in case of breakdown or emergency repairs, since the system must be operated continuously to avoid septic action.
8. Periodic B.O.D. and pH determinations should be made to check the efficiency of the disposal plant.

MILK WASTES

Questions and Answers for S. D. Montagna's Paper

(Prepared by State Department of Health)

1–Q. What per cent loss of raw fluid milk is common in a milk products plant and what is the ordinary waste pollution load per 1,000 pounds milk received in terms of pounds B.O.D. and population equivalent?

A. The milk loss at the H. W. Walker Company, according to the General Manager, is about 2 per cent of the total milk received. The waste pollution load based on 1,000 pounds of milk received represents

833 gallons of raw waste containing 3.8 pounds of B.O.D., a population equivalent of 22.7.

2–Q. Briefly describe the principle of waste treatment at H. W. Walker Company plant.

A. The essential principles for treatment of milk wastes by this activated sludge process involve neutralization of lactic acid and precipitation of protein material to form a sludge. Sufficient aeration and recirculation must be provided to decompose the oxygen demanding substances and to seed the incoming waste. Settling basins are provided to settle out sludge for removal and recirculation.

3–Q. (*a*) What proportion of the total sludge in the final sedimentation basin is recirculated to the aeration basin and how much sludge is removed per day, and what is final disposal thereof?

(*b*) What is the volume of sludge removed from the primary settling basin in relation to the total waste water treated and what is final disposal thereof?

A. (*a*) The per cent of sludge recirculated from the final settling basin to the aeration basin is ordinarily 40 to 50 per cent of the waste flow. This may be reduced, when the sludge is somewhat denser than average, to perhaps 30 per cent, and with a very light sludge it may be increased. It should be kept in mind that no sludge is removed out of the system at the final settling basin. The settled sludge in the final settling basin is merely recirculated to the aeration basin.

(*b*) The amount of sludge removed daily from the primary settling basin is 400 to 500 gallons, or about 1 per cent of the volume of waste treated. The sludge is hauled by tank truck to a nearby field and then plowed under.

4–Q. What is the purpose of treating the influent wastes with lime prior to aeration, activation, and sedimentation?

A. The purpose of treating the influent wastes with milk of lime is to neutralize lactic acid and precipitate the protein materials in the raw waste.

5–Q. What are the average, maximum, and minimum efficiencies in B.O.D., population equivalent and total solids reduction attained at the H. W. Walker Company milk waste treatment plant?

A. The average reduction in B.O.D. was from 545 p.p.m. to 7.4 p.p.m. Population equivalent was reduced on the average from 1,400 to 18 people or a 98.4 per cent reduction. The maximum efficiency was 99.0 per cent. The lowest efficiency, while the treatment plant was operating successfully, was 96.0 per cent. The average removal of total solids was from 797 p.p.m. to 466 p.p.m. or 42 per cent removal.

6–Q. What is approximate cost of construction of a plant to treat waste waters from an establishment processing 60,000 pounds fluid milk per day and what is average daily operating cost?

6–A. The approximate cost of such a plan was $12,000. The operating cost, including the lime, power and two hours labor, is about $3.00 per day.

7–Q. What routine tests should be made to insure and determine efficiency of activated sludge milk waste treatment works and why?

A. The routine tests for the determination of the efficiency of the plant should include 5 day B.O.D., pH, total solids, and volatile suspended solids.

The B.O.D. determinations are an index of the efficiency of treatment and a measure of the pollution load.

pH control is necessary to measure the active alkalinity that must be maintained to insure a favorable medium for bacterial action and precipitation.

The total solids and volatile suspended solids determinations are an index to the amount of inorganic and organic matter that is being discharged by the system. Any increase in the amount of volatile suspended matter would give an increase in the B.O.D. value.

8–Q. Is the activated sludge process for milk waste treatment extremely sensitive to sudden increase in pollution load of influent or to chemical shock.

A. This treatment plant was designed to dispose of the maximum amount of wastes from peak operations so that a sharp increase in pollution load suddenly would not effect the efficiency of the system. The retention period for the average waste flow is about 36 hours. However, the process is sensitive to chemical shock that would greatly increase or decrease the pH in the primary settling basin or aeration basin.

9–Q. Wherein does the activated sludge milk waste treatment at Somerset differ from the so-called Guggenheim process?

A. The Guggenheim process differs from the activated sludge process in that it does not function without the addition of a coagulating agent, usually ferric iron salt.

The retention and aeration periods are shorter in the Guggenheim process. At the activated sludge treatment works in Somerset, the sludge is removed from the system at the primary settling basin before aeration, whereas, in the Guggenheim process, the sludge is removed after passing through the aeration basin.

Stream Pollution

POLLUTION OF CALIFORNIA STATE WATERS FROM THE VIEWPOINT OF SPORTS ENTHUSIASTS *

By Howard Vernon

Not many years ago the waters of the State of California presented to the sportsmen a veritable anglers' paradise. Nature was so abundantly beneficent that the conservation of wild life within the State of California was neglected. During recent years, however, because of the efforts of the sportsmen of California and the fish and game columnists of the different newspapers, laws have been passed calculated to prevent the wanton destruction of fish and game. Today, because of the settled condition of the commonwealth, the increase of population and the extension of agricultural projects, many of those who seek their recreation from the sports have been driven to the interior streams and waters of the State for their pleasures. Sewage, refuse and trade waste, generally from communities, have made it necessary that some means be provided for preserving the purity of the natural haunts of the fish and game of the State.

The unchecked accumulation of sewage in the streams, inlets and bays of the state presents to the sportsmen a most alarming condition. The problem, in view of the rapid increase of pollution, is to preserve the purity of the state waters and, at the same time, guard the health of our citizens and preserve to the anglers the joys which our bays and streams afford. In order to make the state most liveable, it is just as necessary that the purity of the waters of the state be preserved as it is that cities and towns be kept clean. It is, of course, well known that one of the best safeguards against disease is cleanliness and that where polluted streams, rivers, estuaries, inlets and bays are found in settled communities there is the gravest danger of disease. Thus it will be seen that sanitation and true sportsmanship go hand in hand. The thoughtful sportsman really goes afield not alone for the pleasure he derives from rod and gun, but also because he knows that fishing and hunting are health-giving recreation.

The people of California are fortunate in having among their fellow citizens skilled engineers, who are capable of handling the problems of sanitation that have caused the coming together of the members of this convention. The sportsmen of California know only too well the value of the work that the experts upon this subject have done and the necessity for encouraging them to further efforts.

The modern sewage disposal plants, which have been installed at Healdsburg, Petaluma, Burlingame, San Mateo, Palo Alto, Santa

* Presented at the Twelfth Annual Fall Convention of the California Sewage Works Association, Oakland, Sept. 19, 1939.

Clara, San Francisco, and elsewhere, in this state, are examples of the magnificient work that is being done, and those who have achieved these results deserve the praise of our citizens.

If the general public were cognizant of the filth that flows from the sewers into the bays and streams of this state, the resultant effect undoubtedly would be a combined move toward remedying the awful conditions that exist. Is it possible that the flow of this filth from the sewers is to go on until an epidemic breaks out? That surely will be the result before long if the present conditions are not remedied.

No long ago refuse oil was discharged from steamers, small craft and different plants into San Pablo Bay, and because of that fact striped bass and shell fish ceased to be edible on account of the taste of this refuse oil in the bass and shell fish. Wild ducks, covered with this refuse oil, were unable to take wing and finally died. On account of this the authorities took the matter in hand, many arrests were made, and because of the imposition of heavy fines the discharge of this refuse oil into the water has practically ceased. On August 2, 1939, Hon. A. F. St. Sure, Judge of the United States District Court, imposed a fine of one thousand dollars upon a second offender for polluting the Oakland estuary with oil discharged from an old ferryboat which he had just purchased. Fines of this character have a most salutary effect upon such offenders.

In passing it may be interesting to know that other lands are also active in preserving the purity of their waters. For instance, inland towns in Great Britain are compelled to adopt some form of purification as the Rivers Pollution Act forbids the entrance of raw sewage into streams.

About May, 1936, a sample of water was taken from the Napa River. The sample, upon analysis, indicated heavy pollution. I leave to your imagination what the condition of that water is at the present time. There are at least fourteen sewers emptying into the river from the City of Napa and one from the Napa State Hospital. There was an effort made Sept. 29, 1938, on the part of the people of the City of Napa to have a bond issue voted to defray the expense of the installation of a modern sewage disposal plant. Twenty-three votes less than the required two-thirds majority spelled defeat for the measure. The vote was: 1,343 yes; 706 no.

In Marin County there are many sewers that deposit their filth in the streams which empty into San Francisco Bay. Nothing has been done to remedy this malodorous and unhealthy condition.

East Bay municipalities recently decided $15,000,000 was entirely too high a price to pay for the installation of modern sewage treatment plants to prevent the pollution of the water along a part of the East Bay shore.

As an instance of what has been accomplished for the sportsman by the establishment of a sewage disposal plant by the City of Petaluma, I call your attention to the fact that since this plant was installed, the striped bass for the first time in years have come up Petaluma Creek

as far as the City of Petaluma in goodly numbers. Is not this alone a justification for the expense incurred by that enterprising city, without mentioning the other benefits accruing?

Suppose the City of Napa and the State Hospital could be induced to take similar measures. Would not the striped bass in that event again resume their habitat in the upper Napa River? Would it not then be safe to eat shellfish found in the vicinity? Would we not feel more assurance that the ducks shot on the Sonoma and Alviso marshes were fit for human consumption? Could we not trust our boys and girls to go swimming in the warmer waters of the Napa River and its branches without being afraid of their contracting typhoid fever through contact with the polluted waters? Will not the preservation of the health of our people when engaged in healthful sport in unpolluted waters justify any expense necessary to make and keep these waters unpolluted?

Could not the same thing be said of the waters of Oakland Creek and Bay Farm Island?

As a striped bass enthusiast, I had called to my attention that in Oakland Creek certain anglers had selected the mouths of certain sewers as favorite fishing grounds because they claimed, perhaps rightly, that the fish congregated at the mouths of these sewers to feed on the filth were fatter than those caught elsewhere. Is such a condition in the heart of this great city a pleasant one to contemplate? Is not the expense necessary to correct it justified by every human consideration?

Surgeon-General Thomas M. Parran, Jr., Director of the United States Public Health Service, on August 26 last, told officials of East Bay cities that the polluted condition of the east shore line was a very filthy situation and one of the most serious of its type in the United States.

Mayor Henry A. Weichhart of Alameda, President of the East Bay Municipal Executives Association, said that $60,000 has been pledged by the East Bay cities for a survey there within the next two or three months. Let us hope that this survey is followed up by the installation of modern sewage treatment plants to remedy the deplorable condition that now exists.

The San Jose main outfall sewer is a receptacle for the filth from many sewers thereabouts, and that sewer discharges its sewage into a slough that flows into San Francisco Bay.

The seeming indifference or apathy of the populace of various California cities and towns, in regard to the pollution of our waters, must be due to ignorance of the true facts concerning public health and fish and game life.

Mr. J. N. "Ding" Darling, President of the National Wildlife Federation, at a New England game conference in 1938, said "Pollution has turned your rivers into sewers, once flourishing forests are gone, abandoned farms monopolize your countryside and you have to hatch

fish and game birds in incubators because they can't exist in what you have left them of natural environment."

In a recent issue of the *Municipal Sanitation* appeared the following: "Buffalo's City Judge, Charles T. Yeager, has found a method of teaching traffic violators to use caution in their future driving. We recommend the use of this system in the sewage treatment field. When Judge Yeager took the Traffic Court bench every reckless driver was taken to view the city morgue to see the maimed victims of such accidents. It would be equally effective to force all citizens who vote against sewage treatment to take a dip in the polluted waters below the sewers, which would have been intercepted for treatment, had their votes been properly cast." Well said!

The solution of this problem is undoubtedly clear to those who are possessed of expert knowledge in the premises, but in order that practical application of this knowledge may be made it is, as I have suggested, necessary that the people, who after all are the source from which the necessary expense must flow, be educated to an understanding of the crying necessity for sanitation, and the profits in health, in pleasure and in dollars, which the expenditure of adequate sums of money for the purification of the waters of the state will bring to them.

Section 481 of the Fish and Game Code reads as follows:

> Pollution of waters: Substance deleterious to fish, plant or bird life. It is unlawful to deposit in, permit to pass into, or place where it can pass into the waters of this State, any petroleum, acid, coal or oil tar, lamp black, aniline, asphalt, bitumen, or residuary product of petroleum, or carbonaceous material, or substance, or any refuse, liquid or solid, from any refinery, gas house, tannery, distillery, chemical works, mill or factory of any kind, or any sawdust, shavings, slabs, edgings, or any factory refuse, or any lime, any cocculus indicus, or any slag or *any substance or material deleterious to fish, plant life, or bird life.* (Enacted 1933).

In conclusion, I will say, it is my fond hope that all the officials and people of the different cities and towns of California will join in a concerted movement to stop the pollution of the waters of this Commonwealth, to the end that this great state may again enjoy an unquestionable reputation for the cleanliness of its waters and a most healthful place to live and that fish and game may increase and thrive.

(*Editor's Note.* Word has been received of the death of Mr. Vernon, October 15th last, shortly after this paper was presented. He will be greatly missed by his fellow-sportsmen members of the California Sewage Works Association.)

POLLUTION OF NAVIGABLE WATERS OR INTERSTATE STREAMS FROM THE STANDPOINT OF THE FEDERAL GOVERNMENT OR ARMY ENGINEERS*

By Edwin C. Kelton

Lt. Col., Corps of Engineers, U. S. Army, District Engineer, Los Angeles, California

Pollution of waterways, including all streams, lakes, rivers, their tributaries, and the oceans, is a direct or an indirect result of population. As a country develops, its population and business growth is closely paralleled by the growth of those factors which tend to increase pollution of inland and coastal waters. Industrial waste matter, refuse, and sewage; mining waste and drainage water; disposal of garbage and many other such waste matter, entailed by a high-standard development of both population and resources, cause corresponding increase in pollution problems. The increase of pollution of the waters has been gradual and largely unnoticed for many years. As is usually the case, until the needs of the population become urgent and a public demand arises for its abatement, little is done. Public demand generally results in the enactment of needed pollution laws, or their revision, and insistence in their enforcement. Of the various laws that have been enacted by cities, counties, states, and the Federal Government, this paper considers only existing and proposed federal laws concerning the pollution of *navigable waters*, the enforcement of which are or may in the future be within the jurisdiction of the Corps of Engineers, U. S. Army, of which I am a member.

Because of the limitations imposed by states' rights, the existing federal pollution laws pertain primarily to *navigable waters*. During the recent session of Congress, consideration was given to the enactment of suitable federal laws that would prohibit pollution of interstate streams and lakes; consideration being given to health, recreation and wildlife. Similar federal legislation had previously been proposed on numerous occasions prior to 1938, but interests whose operations would be affected thereby have successfully prevented enactment of such federal laws.

Congress, in 1938, passed a bill commonly referred to as an "Anti-pollution Bill." This measure was not an enactment prohibiting pollution, but rather an act to provide for extensive and costly study of pollution problems and for grants and loans to local agencies for the construction and installation of improvements designed to prevent pollution. The President vetoed this bill because he disapproved the manner of granting federal money to local agencies for pollution abatement projects. He did, however, approve the principle of pollution abatement and requested that Congress further consider this subject.

* Presented at the Twelfth Annual Convention of the California Sewage Works Association, Oakland, Sept. 19, 1939.

During the last session of Congress two pollution bills were introduced. One was similar in form to the bill passed during the previous session that the President had vetoed, and which in fact is not an anti-pollution bill. The organization it proposed would be a part of the Public Health Service. The other bill *was* a pollution prohibition bill and provided "teeth" to insure enforcement. Enforcement of this measure would be a duty of the Corps of Engineers.

The second bill just mentioned, as first submitted, was so rigid in its requirements that it created great opposition. In order to make it more reasonable and workable, the bill was modified, and in that form it was favorably received. The sponsor * of the bill states that it is fair to all interests. It would not become effective until two years after passage. He points out that pollution has been the subject of study for many years and that there is little excuse for pollution from a scientific point of view. However, the bill is lenient, since there is a provision whereby the Chief of Engineers can, when it is impossible or impractical to comply with established standards of purity, extend the "period of grace" for five years before violators are recommended for prosecution. The bill further protects local interests by providing that in case an industry can show at a public hearing that there is no "possible or practicable" method of eliminating the pollution, the Chief of Engineers is then empowered to grant "such further extension of time as may be reasonably necessary."

The proponent of the bill also states that the public is entitled to have and use the public waters in an unpolluted condition, that public streams are not public sewers, and that the responsibility for pollution rests with the agencies causing pollution. He states that it is not a proper government function to provide special loans and grants of money to agencies who have neglected to install improvements to prevent pollution. Furthermore, he states that it would be unfair to the agencies that have invested their money in improvements to prevent pollution, to tax them in order to pay for like improvements pertaining to other, or possible rival, agencies that have neglected to make such improvements. The *alternate bill* is said to be a "blind," inasmuch as it is not a bill to prevent pollution and would cost the public large sums of money, and also will merely "put off the day of reckoning" when pollution *will be* rigidly prohibited.

Neither of these bills has come up for final consideration by Congress, but they will probably be considered in January, 1940.

Pollution of navigable waters of the United States has, under existing laws, been unlawful since the passage of the Act of March 3, 1899. Later, special federal laws were enacted concerning garbage and refuse pollution in New York Harbor. Section 13 of the Act of 1899 makes it unlawful to place in, or to permit to be placed in, the navigable waters of the United States any refuse matter of any description, except that flowing from streets and sewers and passing therefrom in liquid state, whereby navigation shall, or may be impeded or ob-

* The Honorable Karl E. Mundt of South Dakota.

structed. Further, the limitations extend to the placing or deposit of any refuse on the bank of any navigable water or tributary thereto from whence it can float or be washed into the navigable waters by tides, floods, or storms.

In 1924 Congress passed what is known as "The Oil Pollution Act." This act makes it unlawful, except in emergency or accident, for any person to discharge, or permit to be discharged, oil by any methods, means, or manner into or upon the coastal navigable waters of the United States *from any vessel* using oil as a fuel for generation of propulsion power, or any vessel carrying oil thereon in excess of that necessary for its lubrication requirements. It is to be noticed in this connection that the law concerns only oil pollution *from vessels.*

I might define *navigable waters* of the United States, since the laws under discussion are applicable only to such waters.

The Federal Court decision states that: " . . . Coastal waters, rivers and lakes are navigable in law which are navigable in fact, and they are navigable in fact when they are used or can be used in their ordinary condition as highways for commerce upon which trade and travel are, or may be conducted in the customary modes of trade and travel on waters, and when they are connected with, or extend to waters of another state or foreign country. . . ."

In connection with pollution of coastal waters, the question arises as to the extent of federal jurisdiction. It is the present practice of the War Department to include within its jurisdiction the coastal waters of the United States to such distance seaward as may be necessary to give full effect to the laws for the protection and preservation of the navigable waters of the United States. This distance is not controlled by any special limitations of three or twelve miles which may have been set up for other purposes. This practice is an assertion of the right of Congress to prohibit the doing of anything which tends to destroy the navigable capacity of any of the waters of the United States. This extended jurisdiction is applicable only to American vessels. The jurisdiction of the United States over foreign vessels, in cases of pollution occurring seaward of the three-mile limit, has not as yet been settled by treaty, as required by international law.

It might seem that the navigable waters, particularly the ocean, are so extensive that pollution would be inconsequential. Unfortunately, this is not the case. Oil and refuse discharged at sea are carried by winds and surface currents for many miles and may eventually float into harbors or wash ashore on the beaches. Experience indicates that in order to prevent pollution of the beaches, oil must be discharged not less than fifty miles offshore, and garbage should be dumped not less than eighteen miles offshore.

Oil and refuse discharged into harbors have little chance to be carried out to sea, and if not cleaned up promptly, they spread and wash onto the harbor shores, cling to boats and piling, or in the case of refuse, sink to the harbor bottom.

In southern California particularly, where the beaches are used for recreation by a very large number of people throughout the year, the presence of refuse, garbage, oil, and sewage washed onto the shore, presents a very serious problem, since such wastes are highly objectionable. Oil has been known to so pollute a beach that for days at a time bathers have found it impracticable to use it. No one likes to picnic on a beach or swim where there is oil or garbage such as grapefruit and cantaloupe rinds, empty crates, or old onions, and other refuse, or near a sewer outfall. Oil is most objectionable to bathers, as it sticks to skin and bathing suits and is usually very difficult to remove. The condition of sewage discharged into the water may be somewhat improved by screening, but it has been reported that screening removes only 5 per cent of the solids, leaving 95 per cent to be deposited on the ocean floor, or washed ashore in a more or less objectionable form. Beaches that are frequently or regularly polluted, particularly those near sewer outfalls, are in general shunned by the public.

Within harbor areas, pollution creates an unsanitary and unsightly condition, and sometimes a serious fire hazard. Floating oil discolors paint on ships' hulls and necessitates their frequent cleaning or repainting. Gases released by decaying refuse have a deleterious effect on paint and hulls of vessels and other metal objects, and is offensive to the public.

Floating oil at times so fouls the plumage of sea birds as to prevent their flying, and thereby causes their death. It also has an adverse effect on fish life, apparently causing an oxygen deficiency, which in turn causes migration from areas frequently polluted. Thus, there is ample reason for the enactment and strict enforcement of pollution laws.

The Corps of Engineers is assisted in the enforcement of the federal pollution laws by the United States Collectors of Customs and other revenue officers, such as the United States Coast Guard. Prosecution is handled by the United States District Attorneys. In the Los Angeles District, the Coast Guard cooperates fully, and patrols are alert to detect and apprehend violators of the pollution laws. The Coast Guard reports all cases to the Engineer Office, and the cases to be prosecuted are in turn forwarded to the United States District Attorney for appropriate action.

The state laws concerning pollution are more inclusive than the federal laws. The Enforcement Division of the State Fish and Game Commission is very active in detecting and arresting violators. That agency cooperates fully with the Corps of Engineers and the United States Coast Guard. These agencies notify each other when cases occur, and members of the two agencies serve as witnesses for either or both state and federal cases, where at least two witnesses are required.

Obviously, there are two types of pollution—deliberate and accidental. The dumping of garbage and other refuse, the disposal of sewage, and the discharge of oily bilge or ballast water onto the naviga-

ble waters are generally deliberate. The spilling of oil while loading or unloading vessels and the breakage of oil pipe lines so that oil is carried onto the navigable waters, etc., are usually accidental. The deliberate type of pollution can be readily avoided. The accidental type is more difficult to prevent, but the use of adequate equipment, its careful inspection, and the institution of proper procedure and training can greatly reduce the number of accidents.

Although designated by law as the "enforcement" agency, the Corps of Engineers takes the attitude that it is better to prevent pollution than to apprehend and successfully prosecute violators. Although strict about enforcement, since the law is mandatory, the Corps attempts to secure cooperation in the installation and operation of proper equipment and the promulgation and enforcement of rules and regulations to reduce pollution.

In many cases the Corps of Engineers, and frequently in cooperation with the State Fish and Game Commission, holds conferences or consults with individuals, concerns, or agencies whose operations involve pollution hazards, concerning proper methods and equipment to prevent pollution. The Corps, of course, is not empowered to require installation of equipment or prescribe operating regulations, but it is eager to assist in considering such matters if the persons or agencies involved so desire, which is frequently the case.

One of the latest cases of cooperation on a large scale is in connection with the fish-canning industry at Los Angeles Harbor, wherein all bilge and waste water from the fishing boats and part of the waste water from the canneries was theretofore discharged directly into Fish Harbor, creating a most undesirable condition. Since the matter of pollution and its prevention has been called to their attention by both the state and the Federal Government, equipment has been installed so that all liquid waste now goes into the sewer system. The importance of keeping oil and solids from the sewers has been emphasized, and screens and centrifuges have been installed for their removal for that purpose. It is interesting to note that, in general, the by-products recovered by these and other installations for eliminating pollution have rapidly paid for the installation cost. Unfortunately, the Fish Harbor pollution is not fully solved, since the waste from the fish canneries, and from boats, which is pumped ashore, is still discharged through a sewer, untreated, into nearby Los Angeles Outer Harbor, causing some pollution.

The cooperation of the major oil companies in preventing pollution has been most satisfactory. Practically all of the oil-loading docks now have special equipment for the prevention of pollution, and some have special booms for use in surrounding oil spills. In some cases, the procedure in loading oil has been modified so as to reduce the liability of pollution, and most companies now carefully plug all vessel scuppers, while in port, in order to prevent oil spilled on deck from flowing overboard. Most oil companies now require their ships' masters to dump bilge and ballast waters at least fifty miles offshore.

Crews of vessels and shore facilities are provided with equipment for, and have been instructed in methods of localizing and removing oil spills so that, although pollutions may occur, they will not spread and become a general nuisance and hazard over large areas.

To prevent refuse and garbage pollution, some ships have installed locked receptacles wherein all such materials are placed while the vessel is in port, and which can be unlocked to permit disposal of the material only by responsible employees, who are instructed that refuse shall not be dumped until the vessel is at least eighteen miles offshore.

The Corps of Engineers, in order to inform all persons concerning federal pollution laws and to call to their attention the need for preventing pollution, has issued notices to all steamship companies, vessel owners and operators, shipping concerns, oil companies, terminal and dock operators, and other agencies whose activities may involve pollution hazards. All such parties have been requested to post and bring these matters to the notice and attention of all employees. Operators of vessels employing foreign crews have been requested to translate and post bulletin notices in the language of their crews. Some such translations have been made and distributed by the State Fish and Game Pollution Detail.

Our office has also recently published and distributed a twenty-two-page illustrated booklet on the subject of pollution and its prevention. This booklet describes the harmful effects of pollution, the causes, and means of prevention, and quotes the pollution laws. And it is intended that by illustrating the various facts, the vessels, steamship companies, shipping agencies, and others, would have a convenient means of calling the attention of all employees to the pollution problem, and that cooperation in this matter would thereby be considerably advanced.

I have with me a few copies of this booklet and shall be glad to give a copy to anyone. If there is an insufficient number to meet the demand, a copy can be obtained upon request, from the District Engineer, U. S. Engineer Office, 751 South Figueroa Street, Los Angeles.

Although in the Los Angeles District new pollution cases average about four a month, the pollution situation is now much improved, the harbor areas are cleaner than a few years ago, and the public beaches are less frequently covered with oil and littered with garbage and other refuse. However, complete elimination of accidents that cause pollution is difficult, and there are still many improvements to be made. The City of Los Angeles still discharges its untreated sewage into the ocean not far from shore, and the City of San Diego discharges raw sewage directly into San Diego Harbor.

It will require continued cooperation of all concerned—vessel operators, shipping interests, and industry in general, especially the personnel "on the ground" and aboard ship, as well as the state and city agencies and in a small way the public in general—to improve the situation so that conditions are satisfactory. It is the hope of the Corps of Engineers that the necessary steps toward pollution elimination may rapidly be accomplished.

Discussion

By A. M. Rawn

Asst. Chief Engineer, Los Angeles County Sanitation Districts

In presenting Colonel Kelton's paper Capt. N. A. Mathias has defined the position of the Federal Government, and particularly the War Department, in the national stream pollution picture; and in addition he sets out the rules which regulate disposal of oil and refuse wastes along tide waters. The paper brings to mind the very narrow limits within which the Federal authorities may operate in the matters relating to stream pollution. This matter having come before the Congress at its last two sessions in the shape of a measure known generally as the Vinson-Barkley bill and having been carefully considered by the National Resources Committee's special advisory group on water pollution, it may be of interest to discuss here briefly the present extent of administrative control over water pollution in the United States and measures recommended for better stream and tidewater cleanliness.

Current administrative control over water pollution in the United States is said by the National Resources Committee to classify under four general methods, as follows:

First.—"Persons suffering damage from water pollution may obtain compensation for that damage by suing the pollutor and proving a just claim; or they may obtain an injunction restraining further discharge of polluting materials." This, in general, is the common law with respect to riparian ownership. To be effective it must be invoked wisely; else, as the late George Fuller stated, "The plaintiff of today may be the defendant of tomorrow." Mr. Fuller continued: "Its (the common law) shortcomings in practice are related to the expense, trouble and annoyance of instituting legal proceedings to maintain riparian rights. In addition, those proposing legal proceedings at common law may be themselves frequently offenders and liable to proceedings by others; thus automatically restricting actions which ordinarily would be sought both by municipal and private corporations." The N. R. C. report goes on to say: "Once damages are proven, it is necessary before an injunction may be obtained, also to prove that practicable means of abatement exist. This entails further expense and further delay."

So far as the average individual, seeking redress for invasion of riparian rights is concerned—he is likely to find common law procedure slow, tiresome, expensive and many times ineffective.

Second.—The second control is: (2) "All States have enacted legislation authorizing State officials to take some action with respect to pollution. Authorizations range from mere direction to study the extent of pollution in some States, to the exercise of police power to force the treatment of any waste in others." Mr. Fuller has commented on this general type of legislation as follows: "In all countries having areas densely populated and with small or moderate sized water

courses, steps have been sought to reinforce control by common law proceedings through the enactment of statutory provisions. These are founded on the police powers of the enacting authority and are justified by the claim which citizens have on their government for protection of public health and welfare." His statement may very well be extended to many states of the Union where areas are not so densely populated and waterways not so small. Thus we find in the several state health and welfare enactments very definite rules about pollution of water and construction of sewers and appurtenant works. In California the Public Health Act; the Fish and Game Act; laws empowering construction of sewers and appurtenant works by municipalities, sanitary districts, sanitation districts, public utilities districts, and a number of penal statutes are provisions designed to ". . . reinforce control by common law proceedings." Of all present measures designed to abate or prevent pollution, the state laws are the strongest and most effective. Extended and amplified in some states and revised to a more uniform pattern in all, they will undoubtedly prove our most useful weapon in the continual struggle against insanitary conditions.

The *third* method of administrative control over water pollution is: (3) "One interstate authority has been established to administer a pollution abatement compact in an interstate area; and compacts which would provide for at least two other interstate authorities are in course of negotiation." The one which has been formed is the Interstate Sanitary Commission, New Jersey-New York; two which are pending are the Ohio River Valley sanitation compact and the Potomac compact. There are informal compacts relating to the Delaware Basin and the tri-State Minnesota-North Dakota-South Dakota conferences. Discussing this type of regulation, the Water Pollution Advisory Committee directs attention to the longer periods which may pass before the compacts may be ratified by all participating states; to the fact that due to local influences, administration of the compact rules may be lax in one state and severe in another, and that there is no ready solution to the problem other than the erection of an over-riding authority, probably the Federal Government. The splendid accomplishments of interstate efforts are not to be minimized. Nevertheless, guidance, by federal authorities would doubtless improve progress.

As a *fourth* measure, the Committee states: (4) "The Federal Government directly controls water pollution only insofar as it regulates pollution of coastal waters by oil and that of navigable waters by substances which impede navigation."

Federal regulation in the State of California, under existing law, can be invoked only to prohibit the discharge of oil from vessels into tidal navigable waters and to prohibit the deposit of refuse matter other than that flowing from streets and sewers into navigable waters. In addition, in California the Secretary of War is authorized to supervise the activities of the California Debris Commission organized to regulate hydraulic mining. These regulations, authority for which is

derived from the Commerce Clause in the Constitution, offer little in the way of relief from pollution and contamination of streams, lakes and tide waters in California or the other states.

In his discussion, Colonel Kelton has mentioned the United States Public Health Service. Because of its authority to determine the quality or safety of drinking and culinary water used on interstate carriers; and by virtue of voluntary agreements with several States, the U. S. P. H. S. exercises an indirect control over water pollution and over pollution and contamination in shell fishing areas. The U. S. P. H. S. is without authority to order remedial measures and must depend upon substantial quarantine to compel abatement.

Regulation of water pollution is now exercised almost wholly by state governments; and, in the opinion of many authorities, should be left there. The N. R. C. recommends that state laws be strengthened, where needful, by the following: state health laws should be drawn to a more uniform pattern so that equal authority is enjoyed by all. Adequate administrative control of pollution, authority and power to determine the nature and extent of pollution, mandatory powers to enforce action necessary to abate pollution, removal of state limitation on municipal bonding when applied to remedial works ordered by the administrative agency, and delegation of power to organize special sewerage districts are recommended. These measures are deemed sufficient to empower state health authorities to investigate into insanitary conditions and to propose and enforce remedial measures.

New federal legislation proposed by the National Resources Committee, while it includes no basic changes in federal law with reference to federal regulation of pollution, suggests inclusion of the following principles in a future congressional enactment:

First.—(*a*) The U. S. Public Health Service shall be authorized to make studies of water pollution and water pollution abatement.

(*b*) To cooperate with other federal, state and municipal agencies in such studies; to assist state officials in the formation and administration of interstate compacts; to review and report to the President on the economic and technical feasibility of pollution abatement projects for which federal financial assistance is requested.

Second.—Federal financial assistance is recommended as follows:

(*a*) Grants-in-aid and loans to state or other public agencies.
(*b*) Loans to industry and other non-public agencies.

Third.—Recommendations of federal aid should be made by the federal agency mentioned in Section 1—preferably the U. S. P. H. S. The remaining recommendations, three in number, relate to the manner in which recommendations for federal assistance should be acted upon and cleared through the various governmental agencies.

It seems to boil down to this: the Federal Government, through the War Department, may continue to guard the navigable waters against

pollution and obstructions of various sorts as at present. The U. S. P. H. S. shall continue to regulate drinking and culinary water on interstate common carriers. Congress shall enact new legislation permitting the U. S. P. H. S. to guide efforts towards anti-pollution throughout the country, offering participating bodies, where desirable, financial aid from the federal treasury. Such action on the part of Congress would leave the jurisdiction and control of state waters in the hands of the states where it is deemed logically to belong; would admit of interstate compacts where interstate waters or watersheds are involved, but would provide that where federal aid was desired an overriding agency, preferably the U. S. P. H. S., would guide the state activities and insure adequate administrative control. It would undoubtedly have one more effect also: inasmuch as there are few state which would care to refuse grants-in-aid and loans from the federal treasury, the enactment of such legislation would in all probability result in the enactment of far more uniform satisfactory and adequate public health laws in each of the several states, as a prerequisite to approval of proposed works by the U. S. P. H. S.

I believe this topic should command much attention from the Sewage Works Associations of America and that each, after adequate investigation, should express itself upon the proposal made by the National Resources Committee.

If I have shot a little wide of the mark outlined in the topic which Colonel Kelton has so kindly explained, I beg his indulgence on the grounds that his able paper appeared to present an opportunity to acquaint you a little with what is being currently considered in the stream and shore pollution field. So far as I am able to see, he has presented the case from the present standpoint of the Federal Government and the Army Engineers so clearly as to leave no doubt in the minds of his auditors regarding the position of either.

Operators' Reports and Suggestions

W. D. Hatfield

249 Linden Place, Decatur, Ill.

SAFE HANDLING OF GAS AT SEWAGE PLANTS *

By L. L. Langford

Eastern Sales Manager, Pacific Flush-Tank Company, New York

Q. What is the primary requisite for the safe handling of gas at sewage plants?

A. To safely handle gas at sewage plants, as elsewhere, the gas should be constantly under positive pressure.

Q. Give an example of what you mean?

A. Examples might include innumerable uses of gas from the familiar kitchen range, through the many industrial uses, as well as the burning of gas in connection with municipal services, such as in incineration and as fuel for combustion engines.

Q. Why should gas be used under positive pressure?

A. There are three reasons: first, to secure efficient burner operation; second, to avoid flashbacks, and, third, to avoid mechanical failure, such as collapse of equipment due to vacuum.

Q. By what means may sewage gas be safely obtained?

A. It may be obtained from a gas holder of the pressure type, limited to the volume within the holder, dependent upon the compression of the gas; or from a holder of the gravity type within the limits of its volume, provided it is properly designed to produce the required pressure and is equipped for heating the holder cup where freezing conditions prevail.

Q. Is there another method of safely obtaining sewage gas at a positive pressure?

A. Yes, it may be obtained directly from a heated digestion tank equipped with a movable gas-tight cover, extending over its exposed area, and designed to float directly upon the tank contents.

Q. To what use has sewage gas been put?

A. It is used primarily as fuel under hot water or steam boilers. It is frequently used as a source of direct heat for incineration and, in small volume, for laboratory work. It is now regularly used as fuel for combustion engines. It was used over twenty years ago in Atlanta,

* Round Table Discussion, Sewage Works Clinic, Pennsylvania Sewage Works Association, June 26, 27, 28, 1939, State College, Pa.

Georgia, as obtained from Imhoff tanks, for cooking and illumination. At the present time it is being successfully used for refrigeration. It may also be mixed with commercial gas and used for innumerable industrial purposes.

Q. From your experience, what points of design of sewage gas systems do you consider to be of primary importance?

A. The piping within the digestion tanks as well as all lines leading therefrom should be of ample size.

Q. Do you mean for normal gas production and use?

A. No. In that section of the system between the digestion tanks and waste gas burner and/or gas holder, piping, meters, relief valves, and all other auxiliaries should be of sufficient capacity to handle peak rates of from two to three times normal flow.

Q. Are condensate traps of importance?

A. Decidedly. Adequate provision for trapping and removing all condensate and slurry at points ahead of, rather than within gas meters, is essential. This generally involves the installation of drip traps at all low points in the piping system.

Q. How should they be designed?

A. Their design should be such as to make impossible the flow of gas into the device during the time of draining or cleaning, which should preferably involve manual operation. Such traps should not require venting, nor the use of a liquid seal.

Q. What about flame traps?

A. It is generally understood that a flame trap of proper design must be provided for each gas consuming device.

Q. What do you mean by proper design?

A. A flame trap should consist of a non-corrosive element of sufficient area and depth to stop flame travel and yet produce a minimum pressure drop. In addition, there should be provided a fused link controlling a positive quick-acting shut-off valve. Neither a flame trap nor a relief trap should rely upon water seals for their operation, due to the possibility of such seals becoming weakened or blown. Also, they should be provided with proper vent and drain, so arranged that the resultant gas will not flow into control rooms.

Q. Where should flame traps be located?

A. In each line supplying gas utilization equipment, as close to the point of flame or combustion as possible.

Q. You mean only in main lines?

A. No, in all supply pipes, including as well small feed or pilot lines to waste gas burners, laboratory burners, feed lines to unit heaters, and others. In these smaller lines, flame cells may be safely used.

Q. As a general rule, where should relief traps be located?

A. Preferably, as close to the source of gas production as possible. If of the diaphragm type, the pilot lines actuating them should connect into the system at a point ahead of gas meters or other like equipment. This permits prompt relief of excess pressure.

Q. Your answer implies the use of more than one relief valve—is one not sufficient?

A. There is no standard design for all gas piping systems. However, good practice includes the use of an individual relief for each tank if of large size, thereby affording the safest and the best possible control of the system.

Q. What observations have you to make respecting waste gas burners?

A. Burners should be elevated sufficiently to insure protection against heat from the burners both to the operator and the structure upon which they are supported. They should be so located as to require only vertical connecting lines. They should be accessible to authorized persons but not to the public.

Q. By what means may gas pressure be observed?

A. The use of oil filled "U" gauges reading directly in inches of water, and connected into two or three points of the piping system provides an excellent picture of the condition within the lines.

Q. Is it necessary to provide a gas holder in connection with digestion tanks equipped with floating covers for the safe use of sewage gas?

A. No. Gas may be used with perfect safety directly from tanks equipped with floating covers. At the Tallman's Island Sewage Treatment Works in New York City, where engines totaling 3500 hp. are in operation, gas is to be used directly from the digesters.

Q. Is it always necessary to include a gas holder to provide a reserve gas supply in connection with gas engines?

A. It is not. Auxiliary gas can readily be obtained from a "tie-in" with the city gas supply, assuming such to be available.

Q. Is there any difficulty in safely using city gas (either manufactured or natural) as auxiliary fuel, combining it with sewage gas taken directly from digestion tanks?

A. With digestion tanks equipped with floating covers there is no difficulty at all.

Q. What essential pieces of equipment are required for the safe utilization of a mixture of sewage and commercial gas, as in connection with a gas-fired boiler.

A. There are required a pressure reducing valve and a gas meter (both usually supplied by the local gas company), a low pressure check valve and a weighted regulator on the city gas side of the system: a

low pressure check valve is used in addition to the usual other equipment, on the sewage gas line.

Q. Is it safe to store gas in the same tank from which the gas is being produced: *i.e.,* a digestion tank?

A. Gas should preferably be stored in a separate gas holder. Constantly positive pressure in a digester should be provided by the digester mechanism without having to rely upon a supply of stored gas, which might not always be available.

Q. With respect to operating rather than design problems, when lack of gas is reported, what action should be taken first?

A. Observe gas pressure by connecting a "U" gauge at the gas dome.

Q. If a reasonable pressure at the digester is shown, what is the probable trouble?

A. Either a trapped or a broken line to the operating gallery is indicated.

Q. Suppose it is reported on good authority that this line is laid to grade and well supported, what should you do?

A. Make a thorough investigation by exposing the entire line if necessary; particularly if it has been laid under fill or under a road. The best laid lines of good authorities frequently settle or break.

Q. If gas is being produced, yet a reasonable pressure at the digester is not observed, what then?

A. Then an inspection of the pressure-vacuum relief valve at the cover should be made to assure that it is adjusted and operating properly.

Q. What is one of the most troublesome reports of plant operators?

A. "My waste gas burner won't stay lit."

Q. Why is this a common trouble?

A. Frequently because of a horizontal line connecting the relief valve to the waste gas burner, in which has developed a low point not provided with a drip trap or drain connection.

Q. Do you mean in the main line?

A. Both the main line and particularly the pilot line. Vertical lines to waste gas burners, properly equipped with drip traps, are not so likely to have the troubles so frequently reported.

Q. May gas safely be relieved at a digester through any type of open regulating or relief valve?

A. Gas should not be released to atmosphere from any point except through a flame trap or flame cell of adequate design.

Q. Does correct design, installation, and operation of gas equipment eliminate the necessity for safety measures?

A. Not by any means. Time does not permit us to list the several devices available for the purpose of detecting hazardous conditions within operating structures. In *Water Works and Sewerage* for last January, Mr. Luther of Freeport, Long Island, N. Y., discusses this subject with a wealth of experience as a background.

UTILIZATION OF SLUDGE GAS FOR POWER PRODUCTION *

By J. F. Hecking

Worthington Pump and Machinery Corp., Buffalo, N. Y.

The sewage disposal plant is too often looked upon as a tremendous burden which increases the bonded indebtedness of the community and is therefore to be avoided in favor of projects which appear to be more profitable. Many communities consider their work well done if they pipe all of their sewage into a passing stream. They then point to the marvelous provision of nature whereby the sewage is rendered innocuous before it travels many miles away. The fact that some other community further down stream may not like the effluent in the source of its water supply, or for its old "swimming hole," is laid to a fastidiousness which can be ignored. Fortunately, progressive legislation is doing much to eliminate this psychological, if not real, hazard.

When it is decided to build a sewage disposal plant, either due to a broadened sense of responsibility or to the pressure of the State Board of Health, the cost begins to loom large. Unless carefully guided by competent sewage works' engineers, corners are cut from the start. One of these "savings," which can become quite expensive, is the omission of properly fitted digestion tanks supplemented by gas engines for the recovery and utilization of sewage sludge gas. It is not our present purpose to discuss the merits of various types of sewage plants but we wish to present the thought that the gas engine is the one item of the sewage works' mechanical equipment which shows a real dollar return on the investment.

The economic advantages arising from the collection and subsequent burning of sewage sludge gas in gas engines have been presented at various times. A small plant in Indiana, using a 45 hp. engine driven generator, reports a power cost of $0.0047 per kilowatt hour, even after 4 per cent investment and an 18 year retirement fund has been added to the operating cost. Another plant, in which two engines are connected to blowers, reports the annual cost of current purchased to have dropped from $13,200 to $1,420 per year as the result of the conversion. The possibility of such savings cannot be ignored and they almost always fully justify the increase in the initial sewage works' cost. It has been stated that an investment of $1.00 per cu. ft. of gas per day would produce current at one cent per kw. hr. after all charges.

* Presented at the Thirteenth Annual Conference of the Pennsylvania Sewage Works Association, State College, June 28, 1939.

It is well known that neither the heating value of the gas, nor the actual quantity generated, develop at a uniform rate. As between one community and another, the volume will be from less than 0.50 to more than 1.50 cu. ft. per capita per day. At average values of 0.6 cu. ft. of 600 B.t.u. gas and 10,000 B.t.u. required per brake horsepower hour, a community of 100,000 population can be expected to keep running 150 hp. of engine capacity 24 hours per day. The city of Peoria, Illinois, with not much over 100,000 population, keeps a 300 hp. generating set and a 500 hp. engine-driven blower running and still wastes several hundred thousand cubic feet of gas daily. Peoria is a somewhat exceptional case in that very large amounts of organic wastes are present in the sewage.

The Engine

Sewage works service presents no new problems to the engine builder who has been producing large, heavy duty gas engines for many years. The service is somewhat similar to that normally required by fuel gas transmission lines and the fuel is much easier to handle than the high hydrogen gases generated in certain coke ovens. Design limitations generally applied are:

> Brake mean effective pressure, not more than 70 lb. per sq. in. Mean piston speed, not more than 1100 ft. per minute. Rotative speed, determined largely by the type of drive, is kept quite low. For example: 720 to 600 r.p.m. for engines under 100 hp., 514 to 400 r.p.m. for engines 150 to 400 hp., and 360 r.p.m. to 327 r.p.m. for larger engines.

The gas engines must necessarily be of the most substantial construction. They may be of open or enclosed type, *i.e.*, with the valve gear visible or covered, but the latter construction is often thought to present the neater appearance. Any engine wherein all of the crankshaft and camshaft bearings cannot be inspected or adjusted quickly through substantial doors on the side of the frame should be avoided as leading to too great a loss in maintenance time.

Equally important is the matter of cylinder construction. Removable liners should be fitted into the cylinder block or frame. With such construction, the cylinder wear naturally resulting from thousands of hours use is quickly offset by replacing with new liners. Further, removable liners can be made of special iron alloys machined all over so as to provide very good heat transfer and long life.

A pressure lubrication system should be carried to all of the running gear, including wrist pins and valve tappets. Engines having cylinders more than 11 in. to 12 in. stroke should be fitted with direct lubrication of the cylinder walls from a bank of sight feed lubricators. Splash lubrication is to be avoided as being conducive to rapid oxidation of the lubricating oil.

Present practice is to limit the temperature on the lubricating oil to not more than 150 deg. F. wherever possible, in an effort to reduce

the formation of a gun-like sludge in the lubricating oil. In order to keep down the temperature, the engine should be fitted with substantial lubricating oil coolers through which the jacket water passes on its way to the engine cylinders and heads. The actual temperature of the water to the lubricating oil cooler is determined by the service to which the water has been put after leaving the engine, but it is in general kept down to 110 deg. F. largely as a matter of preventing the oil cooler from becoming unduly large.

The type of governor should be determined by the service requirements. Centrifugal mechanical governors are quite satisfactory for the smaller sizes when the engines are driving generators, blowers or pumps. Hydraulic relay governors are used for the larger units, particularly where isochronous operation is desirable. Where remote synchronization or speed control is wanted, and current is available, small motors are fitted to the governors. Where current is not available, float or air operated mechanical devices are fitted to the governors.

The gas mixing valves on the engines must be designed to handle a gas which will have a heating value of 550 to 700 B.t.u. per cubic foot. This gas will show about 65 per cent methane, 30 per cent carbon dioxide, small percentages of hydrogen and nitrogen, and traces of oxygen, carbon dioxide and hydrogen sulfide. There is little possibility of gas of this type backfiring so that the major problem is to provide micrometer adjustment of the air-gas ratio so as to get the maximum possible horsepower out of a given volume of gas.

Power Drive

Pumps and blowers constitute the major mechanical units of sewage works power equipment. Screens, conveyors, and other smaller motor powered units are also used. The proper disposition of this equipment over a large area gives rise to the question as to what form the power should have when developed. In some plants, gas engine driven generators are used entirely, while in others all of the power is put into mechanical work through line shafting. The majority of plants here and abroad are developed along lines between these limits.

Sewage works in which all of the gas is used to generate electricity operate at a disadvantage in that they must carry the electrical losses. The overall generator efficiency is seldom better than 94 per cent and motor efficiency about 90 per cent, making the power conversion efficiency about 83 per cent at best. This means that almost 20 per cent of the gas is lost in the process of getting its inherent power from the engine to the driven item. This condition has led most engineers to lay out the sewage works so that the engines are connected directly to pumps and blowers, with effective results.

Recently, a series of test runs were made on a 10,000 cu. ft. per min. blower direct connected to a 460 hp. gas engine. At 8 lb. per sq. in., the nozzle test showed a discharge of 10,000 c.f.m. at the blower and engine speed of 327 r.p.m. Operating against these conditions of service, the engine was called on to develop 407 bhp. which it did with a gas con-

sumption of 8700 B.t.u./bhp./hr. (low heating value). With a discharge pressure of 7½ lb. per sq. in., the blower required 360 bhp. which the engine delivered with a fuel consumption of 9100 B.t.u. Further runs at 7 lb. showed 340 bhp. and 9300 B.t.u.

The variable capacity performance was equally gratifying. Considering only the performance at 8 lb., we find 403 bhp. and 8700 B.t.u. The three-quarter capacity output of 7500 c.f.m. was obtained at 250 r.p.m. where we found 307 bhp. required at a gas consumption of 8700 B.t.u. The one-half load capacity of 5000 c.f.m. was obtained at 177.5 r.p.m. with 210 bhp. and 8900 B.t.u.

It should be noted in connection with these tests that the full load torque of the engine was somewhat in excess of the blower torque requirement. At 327 r.p.m. the gas engine was rated 460 bhp. and test runs of the engine while connected to a test generator showed a fuel consumption of less than 8100 B.t.u. per brake horsepower hour.

The impressive fact is that whether the unit operated at 8 lb. or 7 lb. made little difference in the gas consumption per 1000 c.f.m. Even more important was the ability to show a fuel consumption only 7 per cent higher per 1000 c.f.m. at half capacity than at full blower capacity. It is the unique "flat" performance at high efficiencies under a wide range of capacity and pressure conditions which has brought about widespread use of this type of unit in sizes up to 900 hp.

Generator Drive

Where the volume of gas available fluctuates widely, the engine is often fitted with an induction generator. Such generators are essentially squirrel-cage motors operating slightly above synchronous speed. They require an alternating current source of excitation and this is obtained from the power system to which they are connected. If the municipality is generating its own power, no problems arise over such a connection, but the public utilities do not look with favor on this arrangement and the engineer must first determine their attitude. Units of this type up to 150 kw. capacity have been installed.

The full load rating of the induction generator is obtained at the same per cent overspeed as the per cent underspeed when operating as a motor. If the slip of the given motor is 25 r.p.m. at full load, at a normal synchronous speed of 720 r.p.m. the required full load generating speed would be 745 r.p.m. The corresponding three-quarter load and one-half load speeds would be approximately 738 r.p.m. and 730 r.p.m., respectively.

The engine speed control is usually predicated on the engine being on the line all the time with the engine developing power in proportion to the gas available up to full load. The gas pressure is used as the control medium. When the gas pressure is up to several inches of water, the governor allows the necessary overspeed. As the gas pressure drops, the engine slows down more and more until it finally becomes a motor floating on the line.

The possibility of the generator becoming a motor and driving the engine is to be avoided. The efficiency as a motor will be about 95 per cent and that of the engine about 80 per cent. It is, therefore, obvious that the gas engine-generator size must be kept within the gas availability—otherwise the demand charge will be increased occasionally by about 25 per cent of the size of the unit installed.

The switchboard for induction generators is the conventional general control panel with ammeter, indicating wattmeter, switches, transformers, and circuit breaker. However, it must be fitted with directional relay equipment. This item is of particular importance where automatic shutdown devices are fitted on the engine. In the absence of such a relay, the induction generator acts as a motor driving the engine, which ought to be down because of some functional derangement.

The motoring characteristic of the induction generator is sometimes recalled when the discussion regarding engine starting equipment is underway. It is considered advisable to develop about 75 per cent of full load torque at about 80 per cent rated voltage when the induction generator is so used. Under these conditions, the engine can be motored over and started but the demand charge suffers. It is considered far more satisfactory to install the usual small 250 lb. air-starting set for this purpose and this air can then be used on the governor control to do the actual work of speed regulator, if necessary.

Another type of gas engine generator set is the conventional alternating current generator and exciter operating in parallel with the public utilities lines. This presents no new problems but it does require the development of switchgear for the specific purpose. As in the case of the induction generator, the public utilities are not particularly favorable to the arrangement but if the matter is approached properly and developed correctly, no operating difficulties should arise. Units of this type have been installed up to 200 kw. generating capacity.

The practice in connection with the parallel operating generator is to synchronize it with the bus by connecting it as an induction generator at slightly below synchronous speed and applying excitation to the generator field. The acceleration of the engine, together with the synchronizing capacity of the generator, will then act to bring the generator into synchronism. It is, of course, necessary that the incoming bus be of sufficient capacity to prevent an undesirable drop in voltage when the generator is first connected with the bus and brought into synchronism. Control power for the operations of the automatic switching equipment is obtained from the exciter and a small 220 volt transformer connection with the bus. A battery is furnished for starting and ignition.

When the starting indication is given by the master push button, the engine ignition circuit is completed and the solenoid operated fuel valve is opened. The operator can then start the engine. At approximately 95 per cent of synchronous speed, the generator is connected automatically to the bus and excitation is applied to the generator field. The unit then assumes load in accordance with the system frequency and the

governor setting. The excitation of the generator field is then determined by the voltage regulator.

When the stopping indication is given by the master push button, the control will open the oil circuit breaker and field contactor and shut off the solenoid operated fuel valve and the ignition. With such an arrangement, there is no possibility of the generator continuing to operate as a synchronous motor.

There is always the possibility that the bus is de-energized due to storms or some other occurrences. With this possibility, all of the controls must be built in such a way that manual operation of the entire starting procedure can be carried through without any complication.

Protective Devices

An essential requirement of sewage works gas engines is the ability to operate with minimum attendance. Should they require continuous observation, the financial advantage is likely to be lost. On the other hand, operation of an engine for a very short period after certain derangements take place would completely destroy the investment. These conditions have brought about protective systems which observe and react faster than any attendant could, even though he were near the engine.

The most common protective system is one in which pressure switches are put in the lubricating oil system and in the cooling water system. These are supplemented by an overspeed trip. Should the engine attempt to run away, the water pressure drop, or the oil pressure fall, the magneto and ignition system is grounded and the engine stops as quickly as the rotating masses permit. With this system, a gas shutoff valve is also tripped so that there is no tendency of the engine to keep going or to backfire.

The positiveness of these actions arises from the thought that such derangements are very serious and no time is to be lost by deliberation on the question of whether the pressure drop is serious. When the lubricating oil temperature or cooling water temperature begins to rise, the reason may or may not be serious enough to justify shutdown but the temperature controls often are fitted to react in the same way as the pressure controls just described.

It is not always desirable to shut down the engine without further ado, particularly where it may be only a matter of the cooling water temperature going up slowly. For such applications, limit switches can be mounted in the water and oil system in such a way as to set off a siren or a howler. The noise will then call attention to the engine and if promptly attended to, the derangement may be corrected before the engine shuts itself down.

It naturally follows that when an engine has been shut down in the absence of an attendant, it will take some time to determine just which derangement caused the shutdown. As a method of overcoming this delay, it is the practice to use an annunciator with a suitable number

of drops, each referring to some particular service. Where a number of engines are in use, ten, twenty or more drops are provided, each suitably labeled for a particular source of trouble. The annunciator can be placed in the office, on the switchboard, or at any convenient location, or it may be duplicated at several places.

It should be noted in connection with all shutdown devices that a trip coil or reverse current relay should be fitted in all circuits which are operating in parallel with purchased current or with other engines. In this way the generator will be prevented from acting as a motor and attempting to overload the other units or raising the demand charge.

A gas-engine driven generator operating in parallel with public utility lines is generally fitted with the shutdown and alarm devices covering the mechanical aspects of the engine, but with additional devices for the electrical circuits. One such application has been developed to shut down the engine on:

Overspeed of the engine
High lubricating oil temperature
High engine cooling water temperature
High engine bearing temperature
High generator temperature
Low lubricating oil pressure
Low engine cooling water pressure
A.C. overcurrent
A.C. overvoltage
Loss of generator field.

Heat Recovery

Exhaust heat recovery generally starts with the jacket cooling water. A 200 hp. heavy duty engine with a full load fuel consumption of 10,000 B.t.u. per bhp. hour (low heating value) puts 2545 B.t.u. of this energy into useful work, whereas 3500 B.t.u. goes into the jacket water. At half load, 12,500 B.t.u. may be consumed, with 4300 B.t.u. going into the jacket water. All of this heat, less radiation, can be recovered.

The jacket water circulating rate will vary with the outlet temperature desired. The general practice is to limit the temperature of the water as it leaves the engine to 150 deg. F. with the inlet temperature about 110 deg. F. Where a temperature rise of 40 deg. F. is allowed through the engine, about 10.5 gallons per hour is pumped through. With a 20 deg. F. rise, double this amount is circulated.

The quality of the water being circulated greatly influences the temperature to which it should be raised. Calcium carbonate and other hardness exist in all water to some extent. At a temperature of 140 to 160 deg. F., it is not to be expected that this hardness will precipitate but unfortunately such an outlet temperature is an average value for the entire quantity coming from the engine. Combustion temperatures in the cylinder reach several thousand degrees and the jacket side of the liner reaches temperatures at which solids in solution will precipi-

tate. Accordingly, the scale-forming hardness of the water definitely influences the temperature rise which can be allowed in the engine jackets, heat exchangers, and waste heat boilers.

In sewage works the jacket water is commonly run to the digestion tanks. The desirable water temperature for this heating service varies widely with the nature of the sludge, the construction of the tanks and coils, atmospheric conditions, and other factors. In some installations it is found that the heat in the jacket water alone is more than adequate summer and winter but in most northern installations, exhaust heat boilers are used for further heating.

As a general rule, it may be stated that about 1800 B.t.u. per bhp. hour is recoverable at full load in an exhaust heat boiler. Most applications are made with the water leaving the exhaust heat boiler at 180 deg. F. or less. This water is then circulated directly to the digestion tanks and to the building heating system. The temperature of 180 deg. is usually too high for the digestion tank coils and blending valves are used so as to bring the water temperature to 140 to 150 deg. by the addition of jacket water direct from the cylinders or from the outside.

The utilization of the heat in the jacket water and in the exhaust of internal combustion engines is not new. An old cut shows an exhaust heat boiler connected to a British built Brayton gas engine as exhibited at the Paris Exhibition of 1878. The direct use of the exhaust heat from gas engines under cooking kettles in breweries has been tried. Dr. Diesel argued that the overall thermal efficiency of his oil engine was so high that heat recovery from the exhaust need not be attempted, thereby indicating that it was a live topic of discussion at the end of the last century. It might, therefore, be asked why even greater headway has not been made along this line.

Sewage gas nearly always shows at least a trace of hydrogen sulfide. Fortunately, when the engine is running, the temperature of the exhaust is high enough to prevent condensation and little, if any, corrosion effects are found in the engines. Quite naturally the use of an exhaust heat boiler results in an effort to recover as much of the exhaust heat as possible and, as a result, the exhaust gas is too often cooled below the dew point. Under this condition, small quantities of acid are produced and these have a tendency to corrode the boiler.

A procedure which has considerable justification despite its complication is the use of the two-stage heat recovery. In this arrangement the exhaust heat boiler is used for the specific purpose of generating steam, thereby keeping up the mean temperature difference and keeping the exhaust gases above the dew point. The steam is then carried to a water heater in which the heat in the steam is transferred into the circulating water at any temperature desired.

Another approach to the problem is to put the sludge gas through a scrubber before admitting it to the engine. Hydrogen sulfide up to five grains per 100 cu. ft. is not considered injurious. Where a higher value is found, it is best practice to install a scrubber of the liquid or metallic type.

A typical scrubber to handle a flow of 100 cu. ft. per minute consists of a tank approximately 8 ft. in diameter and 7 ft. 6 in. high. It is fitted with two trays each holding an "iron sponge" about 3 ft. thick. The gas pressure loss through it will be from 5 to 10 ounces. Such a scrubber is installed in duplicate so that the one can be used while the other is being revived, but the piping connections are made so as to permit series use.

In operation the fuel gas is passed through the scrubber, which will remove practically all of the hydrogen sulfide until it becomes saturated. A ready check of its condition can be made with lead acetate paper. When after a two-minute exposure in the gas leaving the scrubber, the paper is found to be turning brown, it will indicate that the hydrogen sulfide content is beginning to exceed five grains per 100 cu. ft. When this takes place, the "iron sponge" is removed from the trays and exposed to the atmosphere, whereby it will be revived.

The life of the sponge will depend on the amount of hydrogen sulfide in the gas and the amount of active Fe_2O_3. It can be revived only two or three times but at 60 cents per bushel for iron containing fifteen pounds of Fe_2O_3 per cu. ft., the cost of complete replacement is low. In addition to the exposure of the sponge to the atmosphere in order to revive it and its occasional replacement, about the only additional attention required is the occasional painting of the inside of the tank with bakelite varnish or similar acid resistant paint. Roughly, the cost of gas purification may be estimated at less than $0.01 per thousand cu. ft. including material and labor.

The builders of waste heat boilers are applying themselves to the corrosion problem. Special construction with acid resistant alloy tubes have been used with some success. A very satisfactory design uses thin stainless steel tubes for best heat transfer but has these tubes covered completely by cast iron rings shrunk in from one sheet to the other. It is to be expected that corrosion effects will be overcome eventually, but in the meantime all specifications incorporating exhaust heat boilers should stipulate that the performance be given at an exhaust outlet temperature of not less than 300 deg. F.

A recent heat recovery arrangement shows very effective results. It is developed as follows:

> The sewage works has installed in the incinerator building, a 360 hp. engine direct connected to a generator. This engine at full load consumes 3,450,000 B.t.u. per hour and converts into useful work 926,000 B.t.u. per hour.
>
> The engine jacket water is in a self-contained loop consisting of circulating pump, heat exchanger and engine. The water enters the engine at 120 deg. F., leaves at 150 deg. F., after having picked up 1,210,000 B.t.u. per hour.
>
> The water heated in the heat exchanger enters at 119 deg. F., leaves at 126 deg. F., and has absorbed 1,150,000 B.t.u. per hour in passing.
>
> The engine exhaust leaves the engine at 900 deg. F., and passes

through an exhaust heat boiler. Water enters the boiler at 137 deg. F., leaves at 141 deg. F., after having absorbed 724,000 B.t.u. Of the total fuel energy, 926,000 B.t.u. is connected to power and 1,874,000 B.t.u. is in recovered heat, making a total of 2,800,000 B.t.u. per hour. Since 3,460,000 B.t.u. is the amount of heat originally introduced into the system, the overall thermal efficiency is said to be 81 per cent.

It will be noted that there is a difference of 11 deg. F. between the temperature of the water leaving the heat exchanger and entering the exhaust heat boiler. This heat is supplied by steam heaters in the adjacent boiler house. The introduction of the steam heaters into the system became necessary because it was decided that the particular sludge digestion tank was to be supplied with 3,850,000 B.t.u. per hour with a water circulation of 350 gallons per minute.

DISCUSSION OF PAPER BY MR. J. F. HECKING, "UTILIZATION OF SLUDGE GAS FOR POWER PRODUCTION"

By B. C. Thiel

Engineer, Cooper-Bessemer Corp., Mt. Vernon, Ohio

The writer agrees with Mr. Hecking's statement that the planning and construction of a sewage disposal plant should be under the guidance of a competent sewage works engineer, as the omission of separate sludge digesters in any sewage disposal plant is a grievous error. No matter how small the original installation, the future growth of the community should be kept in mind and provided for. If the original installation is too small to supply enough gas to operate gas engines of the horsepower required to take the entire load of the plant, engines should be installed to take such portion of the load for which there is gas available. These engines should be connected to that part of the equipment that has the highest demand curve, so as to cut down the cost of purchased power. Then, too, there is always the possibility that the sludge gas production will exceed the predicted quantity, in which case additional units can be installed with a minimum of expense, if future extensions have been planned for.

I believe that the average value of 0.6 cu. ft. of gas per capita per day is slightly low and should be increased to 0.8 cu. ft. per capita per day. This is based on the reported gas capacities of many cities throughout the United States. An average analysis of about fifteen sludge gases is as follows:

	Per Cent
Methane	65.27
Carbon monoxide	0.44
Illuminants	0.15
Hydrogen sulfide	0.29
Hydrogen	0.69
Oxygen	0.28
Nitrogen	2.56
Carbon dioxide	30.32

This gas has an effective content of 602 B.t.u. per cu. ft. and will require 6.32 cu. ft. of air to 1 cu. ft. of gas for perfect combustion. As sludge gas is composed principally of methane and carbon dioxide it can be considered as such for all practical purposes. The carbon dioxide in the gas mixture widens and raises the limits of inflammability. Without carbon dioxide the limits of inflammability of methane are from 5 to 14 per cent of gas by volume in air, whereas with the carbon dioxide dilution shown above the limits are from 8 to 18.5 per cent. Carbon monoxide also has the effect of slowing the speed of flame propagation, thereby damping any detonating effect in the gas engine cylinder. In other words sludge gas is an ideal gas engine fuel.

Mr. Hecking's design limitations are on the safe side. With the newer cast iron and steel alloys, the wear and erosion due to the heat produced by the combustion of the gas in the engine cylinder are being gradually eliminated. This allows us to raise the brake mean effective pressure to 75 lb. per sq. in. without any serious effect upon those parts exposed to the heat of combustion. A mean piston speed of over 1200 ft. per min. is common. A 10.5 in. stroke engine, operating at 720 p.p.m., has a mean piston speed of 1260 ft. per min., and this size unit is being operated at speeds of 900 r.p.m. or piston speeds of 1575 ft. per minute. The modern trend is to higher speeds and higher pressures.

Accessibility is one of the main factors in deciding upon a prime mover. An inaccessible engine is never kept in as good adjustment as an accessible one.

I seriously disagree with the statement that there is little possibility of sludge gas causing a backfire. Any gas that can be used in a four-cycle engine will backfire if the proportions of gas to air are such as to produce a slow burning mixture that is still burning when the new charge enters the cylinder.

All power takeoffs should be direct connected as far as possible. The blowers and main pumps should be direct connected, and a direct connected generator should supply the power for the numerous small motor drives located throughout the plant.

Unless a full time engineer is employed in the power house, the engines, blowers, pumps, and generators should be equipped with protective devices so that, if either the engine or the driven mechanism becomes distressed, the engine either shuts down immediately or a warning signal is operated for a certain period after which the engine is shut down. This must be worked out in each installation.

Under no circumstances should the effluent of the plant be used as engine cooling water, unless it is filtered and treated. The microscopic particles of wood pulp in the water will soon insulate the cylinder liners and heads, and cause trouble.

As far as the engine is concerned, a hydrogen sulfide content of 25 grains per 100 cu. ft. is the maximum for good operation.

Mr. Hecking: I think Mr. Thiel has presented a very interesting discussion of my humble notes. His suggestion regarding provision

for expansion is particularly pertinent. Fortunately, up to now all of the sewage works engineers have adopted a long range view of this work whenever they have gotten any money at all with which to do anything. The major job seems to be to get the money necessary right at the beginning.

Mr. Thiel's suggestion that gas can be figured at 0.8 cu. ft. per capita is very reasonable. Up to now we haven't had any particular case where there was not enough gas available once normal production occurred. This is either due to good engineering or, perhaps, it is due to the high gas output that shows up in some cities.

In connection with the item of 70 pounds which I stated as a proper pressure, I think Mr. Thiel's figure of 75 pounds is equally reasonable. The only explanation which I offer is that I think under the present circumstances any error that is made should be on the conservative side. In the present state of this application or utilization of sludge gas we have felt that we should lean over backwards to make every single plant a success right from the beginning.

Apparently, we have been lucky in this matter of backfiring. We have had no problems at all of backfiring. We have had natural gas engines and coke oven gas engines backfire, but not sewage gas engines.

As Mr. Thiel points out, 25 grains of hydrogen sulfide in the gas is permissible, if you don't have an exhaust heat boiler. As I tried to point out in the paper, the deterrent of the whole scheme of operation, up to now, has been the exhaust heat boiler. If the exhaust gas is cooled down to the dew point, these gases begin to condense and just eat the tubes out of the boilers. For that reason we have adopted the practice—again perhaps leaning backwards—of stipulating 5 gr. of hydrogen sulfide as being permissible for the system as a whole.

MAINTENANCE OF SEWAGE TREATMENT PLANT*

By Harry J. Krum

City Chemist, Allentown, Pa.

The continuity of operation of a sewage treatment plant is only possible if all the units in the plant are maintained in a workable condition. In the larger cities the maintenance of the equipment is in a department especially created for that purpose. Generally, the personnel of that department is under the supervision of an engineer who has as assistants, specialists in electricity, pumps, and machinery. These specialists are provided with shops containing all the machinery and tools for repairing as well as for building new equipment.

Q. What type plant are you going to maintain?

A. There are three types of sewage treatment plants, Imhoff, separate sludge digestion, and activated sludge, operated by the members

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attending this meeting. Since we in Allentown have a plant that consists essentially of sedimentation in Imhoff tanks and oxidation in trickling filters, this discussion will be limited to this type of plant.

Q. What are the units to be maintained?

A. The sewage flows to the plant by gravity and passes through rack screens. These screens are spaced 3 in. apart and are cleaned with hand-rakes. The only maintenance is the occasional purchase of new rakes.

Q. After the sewage passes through the screens where does it flow?

A. The sewage is pumped. The electrical motor driven centrifugal pumps have presented no serious maintenance problem. Only once in the ten years that the plant has been in service has there been a failure in one of the pumps. This occurred when lightning burned out the rheostat operating this pump. The main switch board is serviced, periodically, by the local Power and Light Company and consists of changing the oil in the circuit breakers. The packing in the pump shaft bearing is renewed about every two years. One of the pumps required the installation of a babbit ring to keep the packing in place, otherwise no replacements or repairs were necessary. Occasionally we find it necessary to open the manhole port to remove rags from the impellers. These impellers show no pitting or any other sign of deterioration. The hydraulic valve on the pump discharge is inspected by opening the clean-out head, on Monday, Wednesday, and Friday. Rags and other material are removed at this time so that the valve may close properly.

Located between the 12 and 17 m.g.d. pumps is a four cylinder engine driven by city illuminating gas. In the event of failure of electric power, this auxiliary power unit is connected by a chain drive and clutch with either of the two pumps. Since this engine is primarily a standby unit, it should be available at all times for immediate service; but on the occasion when the previously mentioned rheostat burned out, an attempt was made to use this auxiliary power unit, but failed, because the ignition battery was dead and the oil in the crank case was gummy. The failure of the operator to follow instructions, which were to put this unit periodically in service, might have resulted in serious consequences, especially if all the electric power had failed.

Q. Are there any other maintenance problems in the pump house?

A. The difficulty formerly encountered with the vacuum primers for the pumps has been eliminated by slightly cracking the valve on the suction pipe, thus preventing corks and other light material from being sucked into the vacuum pump as was the case when the valve was completely open.

Q. Are there any other pumps to be maintained?

A. The sludge pump used to convey the settled solids from the detritus tanks to the Dorr fine screens needed only one new brass sleeve in the packing box assembly since the plant was put in service.

Q. What is in the screen house?

A. The screen house contains two Dorr screens, two endless bucket conveyors for the screenings, a hydraulic press, and an incinerator. The only maintainance necessary here was the replacing of a bearing on one of the bucket conveyors and the installation of new electric wiring to the hydraulic press to replace a short circuit in the conduit. The incinerator, which is used to burn the screenings and skimmings from the detritus tanks, still contains the original grating and has required no maintenance service.

Q. Thus far there seems to be little trouble. What about the Imhoff tanks?

A. Imhoff tanks are notoriously free from maintenance charges. The application of paint to the iron railing on the tanks and the replacement of several valves on the water system on the tanks has been all the maintenance necessary. The installation of six 2-in. valves in the water pipe supplying each of the Imhoff tanks proved advantageous, especially in the cold winter months, in that when hosing of a foaming tank became necessary only the water valve leading to the water system on the tank affected was turned on. The ease with which the pipes could be drained in freezing weather encouraged the more liberal use of water for controlling foaming.

Q. What is the next step?

A. The next step is the dosing chamber to the trickling filters. The air release system, which controls the filling and discharging of the trickling filter dosing chambers, failed on several occasions, to function properly due to the clogging of the air release pipe line. When this occurred the tank was taken out of service and the cover of the air tank was removed so that a hose could be introduced into the pipe and the obstruction washed out. The maintainance service on these units was greatly reduced and simplified by substituting a tee for the ell in the pipe leading to the air chamber. The plug on the tee is now removed and the hose introduced at this point with the result that no further interruption of service occurs.

Q. What happens in the trickling filters?

A. The cleaning of nozzles on the trickling filters was reduced 75 per cent by the installation of stationary screens in the Imhoff effluent channel. The labor required to clean the screens is much less than that required for cleaning nozzles. The steel pins in the brass stems of the removable part of the nozzle corroded quite rapidly and necessitated frequent attention in replacements. When spring brass pins were substituted for steel pins, no further deterioration from corrosion occurred. Now, the renewal of occasional worn out pins is a negligible maintenance factor.

Q. I believe that the trickling filter effluent is chlorinated. I also understand that you have three chlorinators. Do you ever need to do any work on them?

A. The three, manually operated, vacuum chlorinators in the chlorine house are completely overhauled periodically. The chlorinators are completely dismantled, the cast iron base painted, and reassembled with such new parts as are found necessary to keep them in satisfactory condition. This is done for the purpose of having a spare apparatus available for immediate service and, also, to familiarize the operators with the function of each unit of the apparatus so that they may more readily spot the source of trouble should it occur.

Q. Of course you have secondary or humus tanks. Do you ever have any maintenance service on them?

A. Several years ago a mischievous youngster threw an automobile tire into one of the final settling tanks. The failure of the overload circuit breaker to function, resulted in a broken housing on the worm gear connecting the motor and the collector mechanism. The large sprocket gear was also broken in two places. Satisfactory repairs were made by welding the broken parts.

The sludge return pumps of the final settling tanks failed to operate satisfactorily until metal plungers and cylinders were substituted for the rubber diaphragm originally installed. The metal houses and exposed iron work on the four secondary tanks are protected from deterioration by the application of paint when necessary.

Q. Do you ever put any sand on the drying beds?

A. The maintenance of proper depth of sand bed, and an occasional replacement of some of the wooden partitions in the open sludge drying beds, keep the beds in a satisfactory operating condition. No difficulty has been experienced with the underdrain system of the beds.

Q. Do you ever test the valves to see if they are in working order at all times?

A. With the many valves in the plant, the only difficulty experienced was with the valve gear in the chlorinating house. The infrequent use of this valve and the severe condition to which it is subjected, cause the gears to corrode. By the liberal application of grease and the periodic manipulation of this valve, this difficulty has been eliminated. Several of the valves with the worm gear exposed became incrusted with coal dust from passing railroad trains. This condition was corrected by attaching an inverted capped pipe over the stem.

Q. Do you maintain a lawn and shrubbery at the Allentown plant?

A. No single item, at a sewage treatment plant, is more impressive to the tax paying citizen than a well kept lawn and properly trimmed shrubbery. The pride an operator takes in the appearance of the grounds and equipment is a visual testimonial to his ability as an operator.

We have three power driven lawn mowers with which to maintain the large area of lawns and we trim and spray the shrubbery, regularly. The results obtained certainly justify the time and labor spent on them.

Q. What would you say is the most important single thing in a sewage treatment plant?

A. It has been truthfully said that the most important thing in a hospital is the patient: it is likewise true that the most important thing at a sewage treatment plant is the operator. If the plant is to be operated efficiently and economically, the morale of the operators must be maintained by true cooperation of the operators amongst themselves. The support of the operator by the councilman or commissioner in securing sufficient funds with which the plant may be operated and maintained, is essential but just as important is a mutual understanding by each of the other's problems.

In recent years the state government requires a uniform budget system for third class cities. In this budget it is now compulsory for city commissioners to show the sum appropriated and expended for maintainance. Our appropriation for this purpose is $400 a year and this has proved adequate.

SAFETY IN SEWAGE DISPOSAL PLANTS *

By N. W. Hartz

Mine Safety Appliance Co., Pittsburgh, Pa.

All of the phases of safety in the operation of a sewage disposal plant could not be covered in one brief discussion; therefore, I will devote most of this talk to those phases dealing with the danger of gases in such plants.

We all know that in the operation of sewage disposal plants combustible gases are generated. We also know that those gases so generated can and do leak from collecting, storage and gas-burning equipment. We further realize that through such leakage disastrous explosions have occurred in sewage disposal plants, with resultant injury to personnel, damage to the plant, and danger to the health of the entire community through failure of their sanitation system. By the application of proper precautions, such explosions can be prevented.

To have an explosion, we must have an explosive mixture of combustible gases and air and a source of ignition. Naturally, air must be present in the plant's atmosphere to support the life of the operating force. It seems to be impractical to exclude air from the operating plant. Therefore, we must accept its presence.

In well-designed plants, explosion-proof electrical equipment is used to exclude the possibilities of sparks from the electrical systems serving as sources of ignition. Furthermore, where plant safety is considered seriously, spark-proof tools are used. In spite of such precautions, it is still possible to have an ignition of an explosive mixture of gas and air in a plant through such causes as the following:

* Presented at the Round Table of the Fall Meeting of the New York State Sewage Works Association, Olean, New York, October 7, 1939.

1. Static charges.
2. Sparks from operators' clothing.
3. Sparks from two pieces of steel striking one another or falling upon cement floors during repairing operations.
4. Carelessness of operators in disobedience to instructions, such as smoking, using improper tools, not deenergizing electrical circuits before making repairs, etc.

This latter group might be termed "the human element" in the problem.

Of the combustible gases encountered in sewage disposal plants, some are odorless. Other combustible gases are odorous but, after continued exposure, they impair the olfactory system so that their odor becomes unnoticeable after a person has been exposed. Still others of these gases are non-odorless. Considering these facts, it is evident that the sense of smell cannot be relied upon to determine whether an atmosphere contains a dangerous amount of combustible gases.

Reliable combustible gas indicators are available. It is true that some of the first instruments of this type that were developed were large and cumbersome and, in some instances, too complicated for ordinary plant operators to use safely and properly. Many improvements have been made in such equipment during the past few years. As a result, we now have combustible gas indicators which are small enough to be carried in an operator's coat pocket and whose operation requires the adjustment of only a single rheostat. Such instruments can be and are used successfully in sewage disposal plants. In some plants, such equipment is used in daily inspection to determine whether there are any gas leaks in the plant. Other plants are planning to have their watchmen carry such instruments on their regular rounds and to take tests at certain designated points in the plant where gas is most likely to be found.

Another instrument that has been developed and is being used to good advantage in sewage disposal plants is the combustible gas alarm. This instrument is intended for permanent installation and continuous operation. In the event that a dangerous concentration of gas accumulates in the atmosphere under test, a warning signal will be operated and the operator can take steps to eliminate the dangerous condition by adequate ventilation and by eliminating the leakage. Modifications of this latter type of instrument are available which permit testing from a relatively large number of points in the plant with a single analyzer. For this service, a motor-driven sampling valve is used. This device is so constructed that in the event a gas is found at any one of the points under test, an annunciator will show at which of the several locations gas is present. By the application of proper pumping equipment, the test points may be separated by several hundred feet. Normally, sampling points for combustible gas alarm installations are chosen where the danger of a seeping gas is considered greatest, such as in pipe gal-

leries, meter rooms, near compressors, from gas engines, burners, valves, condensate traps, pressure-release valves, etc.

It is only by knowing of the hazards in plants that accidents can be prevented. Combustible gas detecting instruments provide a complete picture of explosion hazards and, if they are properly applied, sewer-plant explosions can be avoided.

In addition to combustible gases, we know that toxic gases are generated in the operation of a sewage plant. We also know that these gases can and do escape into the plant's atmosphere. We further realize that plant operators have been asphyxiated by the presence of such gases in the atmosphere in sewage buildings.

If we considered this problem thoroughly, it would be evident that such accidents can be prevented. Prevention of such cases involves three steps:

1. Detection—knowing the true condition of the air to which workmen are exposed.
2. Protection—equipping workmen with proper, personal, protective devices when they must work in the presence of toxic gases.
3. Resuscitation—providing first aid for those workmen who have not observed the proper precautions in their exposure to toxic gases.

Possibly the most dangerous of the toxic gases generated by the digestion of sewage is hydrogen sulfide. While this gas has a very distinct odor, exposure to it for extended periods deadens the sense of smell so that in the presence of a dangerous concentration, an operator will not realize that it is present, or the concentration may increase to a toxic amount without the operator realizing it. For many years lead acetate papers have been available for detecting this gas. The means now most widely used for the detection of toxic concentration of hydrogen sulfide is a detector developed by the U. S. Bureau of Mines. This instrument is designed to aspirate a known volume of sample through a glass tube filled with a chemical sensitive to hydrogen sulfide. The length of stain on the chemical tubes is an index to the concentration of hydrogen sulfide in the sample. Detector tubes retain their discoloration permanently; thus tubes can be filed as a permanent record of tests. Each tube is etched so that the date and place of test can be marked thereon.

Many of the other toxic gases and vapors which may be found around sewage disposal plants are combustible and, if they are present in dangerous concentrations, this fact can be determined by the proper application of combustible gas indicators. Petroleum vapors and benzol are typical examples of these. Practically all of the other toxic gases have a very distinctive odor and, in toxic concentrations, they cannot be tolerated for long periods of time. Examples of these are ammonia and chlorine.

One other condition which may produce asphyxiation in a sewage plant and which is not caused by toxic gases is a deficiency of oxygen. In sludge and septic tanks, which have been drained for cleaning or

repair, operations should not be started until it is shown that the concentration of oxygen there is sufficient to support life, or unless the workmen have been equipped with proper respiratory protection.

The oxygen deficiency in an atmosphere can be determined either by chemical analysis or by the application of the proper type of flame detector. A typical example of a flame detector used for the detection of combustible gases and oxygen deficient atmospheres in mining operations is the Wolf Flame Safety Lamp. While this instrument was designed for mining operations, and is safe in the presence of methane, we cannot recommend it for use in sewage plants. It is recognized that petroleum vapors, benzol, hydrogen and other combustible gases may be encountered in a sewage plant. The speed of propagation of flames of those products is so high that it is felt the wire screen gauge bonnets of the flame safety lamp do not provide adequate protection against explosion. The instrument that is recommended for the detection of oxygen-deficient conditions in sewage plants is the Wolf Oxygen Deficiency Indicator. This device is a modification of the flame safety lamp. It should be used from a position where the atmosphere is known to be free of combustibles. Tests are made by aspirating a sample of the atmosphere to be tested through a length of hose, then through a suitable flashback arrester into the combustion chamber of the lamp. The flashback arrester of this lamp is capable of preventing the propagation of hydrogen or acetylene flame. If a test is made with this lamp and the flame goes out, then the concentration of oxygen in the atmosphere under test is below 15 per cent and it is considered unsafe for workmen to enter without oxygen or air-supplied respiratory equipment.

In supplying equipment for workmen to enter gaseous atmospheres, consideration must be given to the conditions under which they must work. If protection is to be provided only against contaminants in the general atmosphere, such as chlorine from a leaking cylinder, ammonia, hydrogen sulfide, petroleum vapors, benzol, carbon monoxide and smoke, a canister mask is entirely adequate. If, however, workmen must enter enclosed spaces where there may be an oxygen deficiency, then either hose masks or self-contained oxygen breathing apparatus should be available. Such equipment makes the respiration of the workman entirely independent of the air in which he must work. Hose masks provide safe air from the outside to workmen in tanks, buildings, etc. Where hose greater than 25 feet in length are used, blowers should be provided to deliver the air to the wearer. In self-contained oxygen breathing apparatus, a small cylinder of pure oxygen is employed. The latter equipment has many advantages since operations are not confined by hose lengths, as in the case of hose masks, and the apparatus provides respiratory protection against any atmospheric condition.

An inhalator for treating persons affected by gas is a very valuable piece of equipment for use in a sewage plant. While it is possible that some small plants cannot afford the purchase of such equipment, the operating force should be acquainted with the location of the nearest

inhalator to the plant, in the event of an emergency. Usually, a community fire or police department has such equipment for its emergency work and this can be made avaible in case of necessity to the sewage plant. I suggest that each of you determine whether your operating force knows how to obtain the services of the nearest inhalator.

To touch briefly on some of the other safety equipment that should be considered for sewage plant operation, I wish to call your attention to the use of the proper type of portable lamp. All of us know that flashlights or some type of handlamps find frequent usage in such plants. In addition, the users of those lights must frequently climb ladders and travel over narrow walkways where it is desirable that both hands be free for holding on to ladder rungs and rails. We believe that cap lamps, such as used by miners for years, have a definite place in the sewage plant. The headpiece of such a lamp consists of a lens, bulb, and reflector. This is worn on a cap, while the storage battery is worn on a belt around the waist of the user. Such a lamp keeps light focused in the line of vision at all times. Furthermore, it leaves both of the wearer's hands free for handling tools and/or climbing. While many plants are equipped with large searchlights for night use, it is frequently necessary for workmen to perform operations where his own shadow interferes with the light from such sources. This is another place where the cap lamp has a distinct advantage. Furthermore, these lamps have been tested and approved by the U. S. Bureau of Mines as safe for use in explosive atmospheres. Considering the frequency with which combustible gases are encountered in a sewage plant, this fact is extremely important. Great care should be taken to see that ordinary, unapproved flashlights are not used in your plant.

Safety belts are one item of safety equipment that should be available in every sewage plant. If a workman must go into a tank, there is always danger of him being affected by the atmosphere there of injury during his work, or just plain physical failure. To enable the removal of such a person from a tank in the event of an accident, he should be equipped with a safety belt to which is fastened a substantial, tested life line. While a man is working in a tank, two men should be available above the opening to hold the life line and to assist in the removal of the man from the tank in the event of an accident.

First-aid materials should also be provided for every plant. Every safety publication describes the danger of infection from untreated injury. This danger is increased many times in a sewage plant by the very nature of the product which must be handled there. A well-equipped first-aid kit will substantially reduce the consequences and cost of plant accidents.

While it has been pointed out that these appliances are desirable and necessary for the safe operation of sewage plants, it must also be stated that none of this equipment will serve its true purpose unless the men for whom it is provided are acquainted with its proper application. Therefore, training in the use of safety equipment should be scheduled regularly for all sewage plant operators. When an emergency arises, they will then know how to combat it.

SEWER MAINTENANCE *

By Harold J. Huber

Supt. of Public Works, Lancaster, N. Y.

A properly functioning sewer system is next in importance only to a safe and potable water supply in its relationship to the health and welfare of the modern community.

Yet the average village official is more concerned about the outward appearance of his community than the 30 or 40 year old sewer system upon which its health depends. Not until some influential citizen discovers on some bright morning following a rainstorm that the sewer has backed up during the night and plastered his basement with dirt and filth, and with blood in his eye tells the district alderman to do something, or else, does the council become sewer conscious, and the conversation immediately turns to new sewers. When it is discovered that new sewers are an expensive proposition after streets have been paved and house connections installed, the sewer superintendent is usually given a blanket order to do something about fixing up the old sewer, and as far as the council is concerned the matter is settled.

There is no surer way to start a demand for new sewers than to have repeated flooding of basements every time it rains. Yet, the cost of removing the trouble which causes such flooding may be very slight compared to the cost of replacing the entire sewer. Just a small part of what it would cost to build a new sewer, properly applied to the purchase of the proper type maintenance equipment, might render the old sewer almost as good as new, and once such equipment is provided, it is always ready for similar jobs which may turn up in an entirely different location.

In my opinion, if sewer bond issues were stretched just a little bit to include the purchase of maintenance equipment when the sewers are installed, many of us sewer superintendents would look a lot younger with our hats off. True, it will take a convincing argument to make any council understand why you want to buy sewer cleaning equipment before it is needed, but are they buying it before it is absolutely necessary? Despite the most rigid inspection, construction gangs have been known to leave everything from a few bricks to a wheelbarrow in a newly completed sewer. A few years ago, when an inverted siphon which carries a trunk under the bed of a creek in Lancaster began to act up, we dragged the siphon to determine the cause of the trouble. In the 14 in. cast iron pipe we found an old fashioned dinner bucket, with the cover securely closed and the entire thing covered with rust and slime. When the cover was opened we found therein scratched faintly on the metal the name of a laborer who was employed when the sewers were installed 24 years previously. Nobody knows how far that bucket traveled before it came to its final resting place in the siphon—and every foot of sewer in town was said to have been

* Presented at the Spring Meeting of the New York State Sewage Works Association, Albany, N. Y., June 10, 1939.

tested by dragging a ball through it before the village accepted the sewer system from the contractor. Had that dinner bucket chosen to lodge in a high joint, the sewer might have caused trouble within a few weeks after it was put into service—and only the proper type of sewer cleaning equipment would have been able to dislodge this obstruction.

Granting that the proper amount of sewer cleaning or maintenance equipment is necessary, what does the average sewer department need to meet emergencies? Well, there was a time, and it wasn't so very long ago, when we considered that a water-pressure operated turbine ferret, so-called, would meet any problem which we might face in the matter of sewer stoppages or emergency sewer cleaning. These self-propelling nozzles, while they are without a doubt very effective pieces of first-aid equipment, are far from a superintendent's dream of a cure-all for sewer troubles. In a municipality like Lancaster, where we buy our water wholesale and distribute it through our own mains at a small margin of profit, any water pressure-operated sewer cleaning device is expensive to use regardless of its efficiency. Added to the cost of water needed for their operation is the cost of necessary pressure hose, not only able to withstand the pressure of water from the inside but also resistant to the abrasive action of the sewer tile and its multiple joints on the outside. Add to this the cost of labor necessary to handle a fire hose under pressure, and subtract the fact that unless a drag cable is attached to the ferret, the distance which it will travel under its own power is relatively short, and it becomes very apparent that the results obtained are very much out of proportion to the amount of labor involved—because, with a ferret, or self-propelling nozzle, about all that you have done is to bore a four-inch hole through the obstruction, and the sewer is far from clean.

In my opinion, there is nothing superior to the cable and bucket method of cleaning, but the cost of cleaning sewers by this method is dependent to a great extent on the accessory equipment which is used. Take sewer rods, for instance. There are rods and rods, some good, some entirely unfitted to the type of work involved. In Lancaster we have used at various times five different makes of sewer rods, including every type from the ordinary hinge coupling to the hook and screw type rod. Everything being considered, we have found that the 120 degree type of rod, which can be coupled and uncoupled on the surface of the ground and fed into or pulled out of the sewer in a continuous series of rods, is the quickest and cheapest operated wooden rod on the market. With due respect to flexible steel sewer rods, may I say that we have never used this type of equipment, but I understand that the use of these steel units has worked out very well since they too are coupled and uncoupled on the top of the ground. Sewer rods, however, are used chiefly for the purpose of guiding the cable from the sewer cleaning machine through the sewer, but as far as doing a cleaning job with rods and rod attachments is concerned, we consider this also just a first-aid measure. In cases where sewers have stopped up and manholes up the sewer line are filled with water, we use the rods with just a leader

attached to punch through the obstruction and release the water which has been held back. After the sewers have drained out we immediately bring the sewer cleaning machines into action. Before dropping the subject of rods, may I say that some time ago we purchased a flat, flexible steel tape, 100 ft. long, about ¾ in. wide and ⅛ in. thick from a plumbing supply house for emergency jobs, and that this has proved to be a very valuable piece of first aid equipment also. When a section of sewer between manholes is found to be blocked, we immediately resort to this flexible tape as a possible means of punching through the obstruction. The tape is first fed into the sewer for its full length from the lower end. If no results are accomplished, the tape is pulled out and fed into the blocked sewer from the upper end, and since this work can be done from the top of the ground, manholes half filled with water are no great hindrance. In nine out of ten cases, whether by luck or otherwise, we have reached the obstruction in the sewer with the tape from one end of the blocked section or the other, and it wasn't even necessary to send a man down into the manholes until the cleaning machines were put into action. Had it been necessary to couple rods to reach the obstruction, much time would have elapsed before even temporary relief was forthcoming.

Our cleaning equipment consists of two windlass-type machines mounted on four wheeled trucks, together with various sized cleaning buckets and an expanding root cutter. We have found that we made a good investment by purchasing the truck-mounted windlasses, since they can be pushed from one manhole to the other by hand; and except for towing them to the job in the morning and away from it at night, they do not tie up any motor trucks for any great length of time. This, however, is not the case with the stationary windlass, which must be moved from manhole to manhole at the expense of tying up a truck and a truck driver's time. The cleaning buckets are of the type which open when they are dragged forward and close when they are pulled back. The expanding root cutter we consider invaluable. It can be used in all sizes of sewer from 6 to 24 in. and does a great job of sawing off the roots inside the tile. We have used this accessory on jobs which looked like dig-ups at first glance and by proper manipulation finally cleaned the tile completely of huge accumulations of roots. One section of 15 in. tile was so badly clogged with roots that we had difficulty in getting the rods through in order to pull in the cable, yet by starting the root cutter at its smallest size and gradually expanding it as we worked, we finally removed the entire root mass. You may wonder how such a large amount of roots was ever allowed to accumulate. Excepting a self-propelling nozzle, the village had no sewer cleaning equipment whatsoever until 25 years after the sewers were installed, and the files of the State Health Department are filled with complaints of flooded cellars from Lancaster residents. When sections of sewer, such as the one I have just referred to, gave trouble, and the self-propelling nozzle wasn't equal to the job, the old method of punching a hole in the side of a manhole and installing a bypass to the nearest ditch

or creek was resorted to in lieu of cleaning the sewer. However, even this system was ineffective when the mains were loaded with storm water, hence the complaints.

When we speak of stormwater, we have a real subject to discuss. Without trying to prescribe any remedy for the stormwater situation, I'll just tell you what some of our experiences have been at Lancaster. When I was given charge of the sewers, naturally one of the first things that I tried to find out was the source of the huge stormwater load which piled down into the disposal plant every time it rained. So the first thing that I did was to go back into the village records to the time when the sewer system was built and the disposal plant installed, which happened to be a joint proposition. The system and plant were constructed in 1908, I found, and six months after they had been accepted and turned over to the village, there was a notation in the records that the plant had been flooded out during a spring thaw to a depth sufficient to submerge even the electric motors. This, with a brand new sewer system and a population about half of what it is at the present time. Further investigation revealed the fact that within another year, the plant was flooded out on several other occasions, the motors and pumps removed to a higher level, but here was a brand new sewer system that leaked like a sieve and couldn't be replaced. Right then and there I felt like throwing up my hands, because this record indicated that the joints were poorly made and had leaked right from the start. So the next best thing was to look for the source of the storm water and attempt to divert it wherever possible. The first problem which we attacked was that of roof leaders. We employed a man to visit every home in the village, check upon the roof connections, and to report any case where roof leaders were connected to sanitary sewers. Following his inspection, we sent notices to all property owners who maintained such connections to disconnect them at once, and with a few exceptions which had to receive a little harsher treatment, got some excellent cooperation from home owners throughout the village.

Next, we made an inspection trip on foot over every sewer line on unimproved property and across private rights-of-way. Here we found some real cases of storm water infiltration. Sewer trenches which had been improperly backfilled and insufficiently tamped, and where the backfill had settled anywheres from six inches to two feet below the surface of the ground, had become drainage ditches without outlets, and here and there were huge washouts where the water was finding its way into open joints. Sewers had been laid along the banks of brooks and drainage ditches, and what at first appeared to be muskrat holes along the banks were found to be washouts into the tile. At practically every point where a drainage ditch crossed a sanitary sewer, we found some kind of a washout, despite the fact that cast iron pipe, according to the records, had been used for such crossings. Upon investigation, we found that the cast iron pipe was there all right but that the ditch had widened out and the water was entering the sewer at the point where cast iron pipe and tile joined. Along one paved road

in the village, which had been improved after the sewer system was installed, we found that the bottom had dropped out of the drainage ditches alongside the highway at nearly every point where the maps indicated that a Y connection had been installed. Upon digging up these connections, we found that anything from bricks to tin had been used to close the open end of the Y after the connection from the main sewer had been extended to the outer edge of the pavement. One generous source of storm water was discovered to be a concrete box culvert crossing under the same highway and which carried surface water to a nearby creek. The culvert was a concrete box 2 ft. square, with a concrete bottom about 4 in. thick. Investigation showed that the bottom of the culvert had settled away from the sides for about ¾ in., and that the ditch water was running through these crevices into the sanitary sewer beneath. We recommended that the State Highway Department, which maintained this particular thoroughfare, jack a corrugated metal pipe into the culvert and seal the ends to eliminate any further possibility of leakage. By-passes which had been installed at manholes where the sewers backed up because of internal obstructions were found in many cases to be taking surface water into the sewer rather than to discharge the overload.

With the help of relief labor we began a thorough rehabilitation of the sewer system in 1933. Sewer cleaning equipment was purchased, and one crew set out to drag every foot of sewer in the village. Other gangs were put to work digging up spots where washouts were evident, repairing the defective joints in the tile beneath, and tamping the fill securely back into place. Sewer trenches which had settled and were serving as surface drainage ditches were filled to the proper level by the use of fresh fill which was hauled in and properly tamped. Other drainage ditches which had wandered away from their former courses and found openings into the sewers were relocated. Where sewers paralleled large brooks, the entire sewers were uncovered and recaulked. At points where drainage ditches crossed the sewers, the ditches were enclosed with tile rather than to disturb the sewer trench.

Results obtained and conditions discovered with the sewer cleaning apparatus were a good indication of the general condition of the sewer system. Where large quantities of sand and gravel were found in certain sections of sewer, we looked for trouble along the line and usually found it. Defective sewers reported by the cleaning gang were reported, and a follow-up crew went to work immediately to remedy the trouble. Much as we disliked to recaulk the joints with cement mortar, we found that they had leaked so long and were so badly coated with slime that no bituminous poured joint would hold, so we recaulked the joints with a rich mortar after thoroughly cleaning out the old caulking material which apparently had been a very lean mixture of cement and sand.

That first sewer cleaning taught us a lot about sewer rods. When the sewer cleaning equipment was purchased, we obtained with it about 600 feet of 90 degree, hinge-type rods. For a short time we experienced

no trouble with the rods whatsoever. Then one day the cleaning gang foreman reported that the rods were hung up at an apparently solid obstruction in an 8 in. tile. The follow-up gang dug up the sewer at the point where trouble was indicated, and instead of an obstruction merely found an irregular joint. The hinges on the rods had begun to wear, the rods buckled against the top of the sewer and one of the couplings had caught on the high joint. Repetitions of this occurrence came frequently after that, and after a conference with village officials we decided to purchase some hook and screw type rods. In due fairness to this type of rod, let it be said that they absorbed a terrific amount of punishment in some districts where the sewers were almost entirely obstructed by roots. They possessed the disadvantage, however, of requiring two operations to couple each joint, and the time lost in coupling and uncoupling more than offset the advantage of having a tightly-joined, solid rod to work with in the sewer. Furthermore, they were man-killers, in that they could only be coupled in the bottom of the manhole, and that a man had to almost stand on his head in small manholes to join them together. Because this type of rod was so hard to handle, it was the custom of the cleaning gang to leave them coupled together and shove them from one section of sewer to another, leaving them in the tile overnight after anchoring them to a ladder rung. This soon resulted in the deterioration of the wooden rod at the point where it socketed in the coupling, and when the couplings began to pull off from the wood shaft of the rod, it soon was apparent that the rods would have to be replaced. When they were finally replaced we made a trial purchase of 120 degree rods, which can be handled almost entirely above the ground, and have met with success with this type of stick even under the most trying conditions.

After cleaning all of the sewers and repairing all of the washouts which were visible above ground, diverting drainage ditches and generally overhauling the sewer system, we naturally expected that our troubles were about over. A careful survey had indicated that there were absolutly no catch basins connected to the sanitary sewers, roof leaders had been disconnected, and we awaited the rainy season to see just what had been accomplished. When the rains did come, we found, much to our dismay, that while the condition had improved somewhat it was still far from corrected. Every drop of sewage which enters the disposal plant must be pumped, and as the location of the plant is such that even the use of a by-pass is impractical, we again found that the pumps were overtaxed by storm water infiltration. Since elimination of this added flow was important from an economical as well as a sanitary standpoint, we decided that it was worth our while to find out just what was happening to the sewer system at times of rainfall. So when the next heavy rainstorm came a crew of men armed with pickaxes went along the sewer lines, opening manholes and carefully noting the difference in flow from one to the other.

That was when we got the most disagreeable surprise of all. We found that the cause of the trouble was again in poor construction—not

only in the sanitary sewers but in recently laid storm sewers on paved streets. These storm sewers, which had been laid in advance of the paving, had literally been tossed into the ground without any regard for the proper caulking of joints or back filling of trenches. Invariably located above the deeper sanitary sewers, they were discharging the majority of the load of water which they collected in the catch basins on the street through the open joints in the tile into the sanitary sewers below. Where the storm sewer was located a considerable distance away from the sanitary lines, we usually found that this leakage out of the storm sewers was entering the house connections into the sanitary sewers. Where the storm sewer was located in close proximity to the old sanitary sewer trench, in many instances the water was finding its way directly into unused Y connections along the main line. The amount of water which the storm sewer was discharging at its outlet was only a fraction of what was being collected on the road surface; and the rest was taking the path of least resistance, directly or indirectly into the sanitary sewer system.

Here is a real problem, involving an expensive repair program. It costs real money to dig up concrete paving and replace it, but in many instances that will be our only alternative. In others, we may find it practical to install additional outlet lines from the storm sewers to offer a path of still less resistance to the collected storm water. It seemed unbelievable that surface water should be entering the sanitary sewers along hard surfaced streets, but that was just what was happening, not from above but below ground. It is very imperative that the storm sewers be kept scrupulously clean and free from obstructions to remove any resistance to their flow, because the slightest accumulation of material would merely force the water out of the joints and into the nearest sanitary sewer connection.

All of which goes to prove that careful construction and rigid inspection are just as necessary in storm sewer installations as they are in the laying of sanitary lines. Joints should be just as tight, because tree roots have no conscience; and sanitary sewer laterals weren't inspected so rigidly a few years ago as they are now. The efficient life of any sewer is dependent entirely upon the type of joint installed in the first place, and proper inspection by village authorities of any trunk sewer installation is just as important as the rigid scrutiny of the plumbing inspector who passes upon lateral installations. We have learned from sad experience that a lateral sewer is only as root-proof as its poorest joint, and after paying for several dig-ups where the house sewer was blocked because roots entered the Y connection, where some plumber "got by" with a poor joint despite the vigilance of the inspector, we are determined that there shall be no repetition of this experience in the future. Whether it be for storm or sanitary sewers, my preference is decidedly for the poured bituminous joint, as our experience with this material has been highly satisfactory.

Despite the fact that we in Lancaster are still handicapped with a set of sewer and water ordinances that are as out of date as a top

buggy, we still have hopes that some day the council will adopt an air-tight set of ordinances regulating the installation of sewer connections. Many of you fellows are fortunate in having a modern set of ordinances to work with—a set of regulations which specifies in plain terms the size, material, and type of joint to be used. Last summer I watched with dismay as a Buffalo plumber installed a 4 in. connection into the main sewer for the $80,000 Lancaster postoffice. Despite all of my objections and arguments, and despite the fact that there were no less than ten fixtures connected to it, this contractor installed a 4 in. cast iron pipe lateral from this modern building. Root-proof, certainly, but it doesn't take much to block a 4 in. sewer. Yet there was nothing in what the village fathers call ordinances to prevent this obviously ill-advised construction.

The lack of improvement in economic conditions has forced our sewer department to venture further and further into the field of lateral sewer maintenance; yet we have been successful thus far in confining our activities to the flushing of laterals with fire hose. Ordinances or no ordinances, if a house sewer blocks up and the owner of the property is one of the many victims of the depression and unable to afford the services of a plumber, we have the choice of allowing a health menace to exist on this man's property or trying to blow out the blockade with water pressure from a fire hose. When the stoppage is something easily removable, the job is done at little or no cost to the village. But when we encounter root conditions, and after wasting a lot of time and water must admit that ordinary measures will not afford relief, we must necessarily disregard the ordinances to the extent of allowing the property owner to dig up the sewer himself and loan him the tools to remove the obstruction as best he can. For flushing the sewer, we make a nominal charge of two dollars which is usually added to the current water bill.

One problem which the Lancaster sewer department has to contend with, that is not common to all other municipalities in this locality, is that of maintaining sewers in what we call the flood area. Due to circumstances over which we have no control, a good-sized portion of the village is visited about twice each year by floods from Cayuga Creek, which overflows its banks to such an extent as to close highways to traffic. In 1937, the most disastrous flood in its history visited Lancaster, and water reached a depth of six feet on some village streets. Homes were flooded to a depth of two and three feet on the first floor, and almost a half million dollars' worth of damage was done. The flood water was heavily laden with silt, which was deposited generously on and in everything. Sanitary sewers in this area were loaded with mud, and we had a terrific job getting them open. Now, two years later, these same sewers in the same area still give trouble. Sanitary sewers on some streets have been cleaned as often as five times since the flood, and each time great accumulations of mud were removed. House connections in the area are a continuous source of trouble, the vent traps

loading up with silt two and three times a year. Where the silt comes from is a question—probably from underdrains around homes in the flood area which are gradally freeing themselves from the load of mud left by the receding water. To these victims of the 1937 disaster village authorities extend all of the facilities of the sewer department. No charge is made for flushing out lateral sewers in the flood area, nor will any be made until they cease to discharge the accumulation of silt with which they are gorged.

Despite this one unusual angle, however, our problems are the same as yours. Far be it from me to make any excuses or to indict publicly any village government for laxity in inspecting the installation of improvements. The Village of Lancaster is responsible for its own problems, as far as the sewer system is concerned. But what has happened in the past will never happen again, and we hope that other sewer departments will profit by our experience. Profit means gain—a real dollars and cents gain in reduced operating costs and increased efficiency.

A SAMPLER FOR DISSOLVED OXYGEN TESTS ON STREAMS AND RESERVOIRS

By A. Adler Hirsch

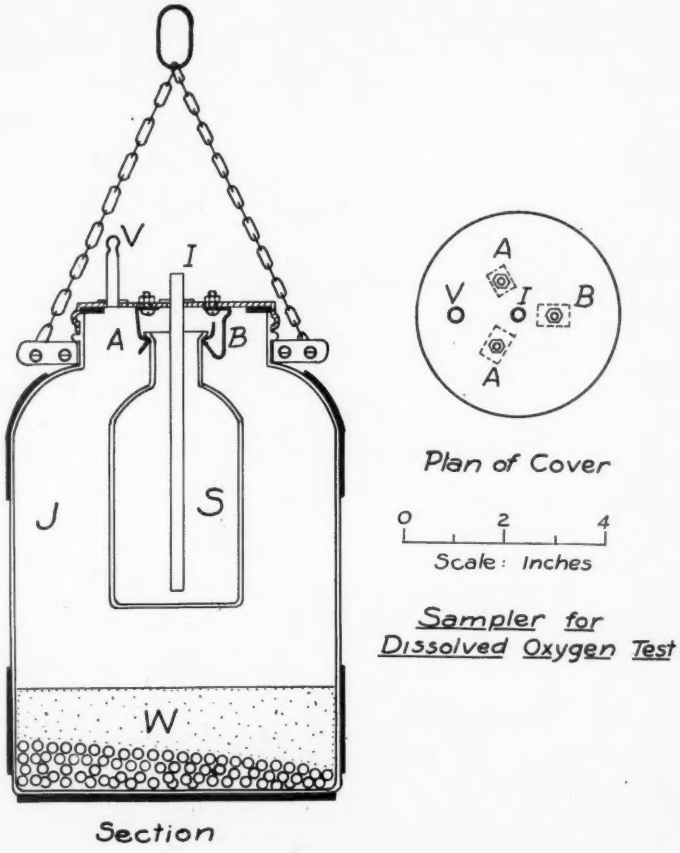
Chemical Engineer, Sewerage and Water Board, New Orleans, La.

A successful dissolved oxygen sampler requires a means for filling without contacting with displaced air and a provision for flushing out the sample bottle volume several times during collection. The most compact arrangement of sample bottle, flushing space and seal is the telescoped device of Greenfield and Mickle (1) in which the sample bottle is suspended inside a larger sealing reservoir. The design described below is patterned after that of Greenfield and Mickle but differs mainly in the use of a metal screw cap, details of the internal suspension, and the method of weighting.

Referring to the sketch, *J* is a wide mouth glass jar having a quarter turn metal screw cap seating on a rubber gasket. The inlet *I*, a thin walled copper tube, and the vent *V*, a brass nozzle, are both soldered to the cap, the joints being strengthened and stiffened by washers. Both tubes extend above the cover as shown to allow rubber hose connections when needed. Two phosphor bronze clamps bent according to the outline at *A*, and one of type *B* are placed as illustrated in the cover plan to provide a three point support for the B.O.D. sample bottle *S*. These clasps are fastened to the cap by brass bolts which fit through short radial slots so that adjustment might be made to accommodate different sizes of bottle mouths. The assembly is weighted at *W* by lead shot heaped somewhat to one side and covered by a retaining layer of cement mortar. Eccentricity of the shot load and slight irregularity

of the jar interior prevent movement of the ballast when the jar is inverted.

The external jar *J* is protected against breakage by a rubber mat cemented on the bottom and by two wide rubber bands, cut from an old inner tube, stretched around the jar near the bottom and over the shoulder. Suspension of the assembly is by a chain bridle attached to a yoke bolted underneath the lug below the cap screw.



Sampler for Dissolved Oxygen Test

The main advantage of this device is that sample bottles may be installed or detached with a minimum of manipulation. A sample bottle is placed in receiving position on the screw cap by the same simple motion which inserts the inlet tubing. Release of the sample bottle is accomplished almost as quickly, merely by flexing hangar *B* outward while withdrawing the sample. The copper inlet tube displacement is smaller than the stopper volume hence there is no necessity for the addition of water externally to avoid air bubbles.

This design requires no external rack either for carriage or weighting. Only commonplace materials are needed for its construction. The protruding inlet allows sampling from shallow pools by attaching a rubber hose at *I* and applying suction at *V*. For precise depth sampling a long rubber tube may be slipped over the vent and also attached by cord to a plug or cap on the inlet. However, in general the apparatus sinks rapidly enough so that the sample bottle is finally filled at the depth desired.

REFERENCE

1. R. E. Greenfield and F. L. Mickle, Illinois State Water Survey, *Bulletin* **16**, 197–201 (1918–19).

Federation Affairs

Plans are under way for expansion and further development of the Federation, in accordance with a resolution passed at the January, 1939, meeting of the Board of Control. A Committee for Expansion and Reorganization was appointed by Chairman Emerson, and preliminary meetings were held in New York City, attended by those members able to be present. A progress report was prepared by them, which was submitted to members of the larger committee who were present at the meeting of the Federation Board of Control in New York City on January 18, 1940.

The members of the Commitee for Expansion and Reorganization are listed below, and those present at the January 18th meeting in New York City are marked with an asterisk:

*C. A. Emerson, Jr., *Chairman*
*H. E. Moses, Harrisburg, *Ex-Officio*
*Wm. W. Buffum, N. Y. C., *Ex-Officio*

*A. S. Bedell, Albany, N. Y.
*Alexander Bell, San Francisco
*Morris M. Cohn, Schenectady
*W. W. DeBerard, Chicago
*Linn Enslow, New York City
*Gordon Fair, Cambridge
*F. W. Gilcreas, Albany
*Chas. G. Hyde, Berkeley
F. W. Jones, Cleveland
Dana E. Kepner, Denver
Max Levine, Ames
W. S. Mahlie, Fort Worth
*F. W. Mohlman, Chicago
*N. L. Nussbaumer, Buffalo
*W. J. Orchard, Newark (Mr. Eastwood)
Langdon Pearse, Chicago
*Wm. Piatt, Durham
*Willem Rudolfs, New Brunswick
Abel Wolman, Baltimore

Sixteen of the twenty-two members of the Committee were therefore present at the meeting in New York City. The progress report prepared by the local group was submitted to these sixteen members and discussed by them. After some modifications the report was adopted and submitted to the Federation Board of Control at the Annual Meeting on January 18, 1940. Time did not permit submission of the progress report to the remaining six members of the Committee prior to the Annual Meeting of the Federation, but copies have been sent to them for their consideration. The large majority present and voting in favor of the report indicated that a favorable vote might be expected from those members not present.

The Board of Control of the Federation received the Committee Report and adopted it as the authorized plan for expansion and strengthening of the Federation. The Report follows:

January 17, 1940.

FEDERATION OF SEWAGE WORKS ASSOCIATIONS PROGRESS REPORT OF COMMITTEE FOR EXPANSION AND REORGANIZATION

The Committee appointed to consider methods whereby the Federation of Sewage Works Associations can more adequately serve all branches of the field has had several group meetings and one general meeting. In addition, there has been much interchange of views by correspondence.

While the accomplishments of the Federation have been noteworthy and have materially exceeded the expectations of those present at its organization more than a decade ago, the Committee is of the opinion that its activities must be broadened if it is to continue as the recognized national representative association in this rapidly growing field. It is believed that to exert such increased influence there must be closer cooperation of the various member associations and some kind of central organization to coordinate activities and assume the increased responsibilities of management which will necessarily attend such activity.

The Committee believes that a merger of the scientific activities or executive management of the present Federation with those of any other organization now existent would be detrimental to the best interests of all concerned.

The Committee has found that there is a definite demand in certain quarters for a national sewerage association to serve the entire field of sewerage and sewage treatment; provide a national convention where there could be an interchange of views by representatives from the entire country; and furnish opportunity for manufacturers of equipment to exhibit their products to full advantage.

It has been suggested that such an association be formed and patterned along the general lines of the American Water Works Association. However, the Committee is definitely of the opinion that launching of such a national association would be a serious error and is not at all necessary as it will be possible to modify and extend the activities of the Federation to adequately meet the needs of all branches of the field. The prestige attained by the Federation during its eleven years of independent existence and the power and influence which can be exerted by its 3,000 members in this country and abroad must be recognized and protected.

Manifestly, such an expansion will require changes in the present organization and necessitate provision of funds to finance a central office, further committee work, and to care for many other necessary expenses.

It is clear that the growing interest of manufacturers of equipment must be given recognition and it is believed that through such recognition, together with increase in frequency of publication of SEWAGE WORKS JOURNAL which will increase its value as an advertising medium, necessary funds may be made available for such definite increase in the value and prestige of the organization. However, it is not felt that such greater worth and influence can be attained without more liberal support from the individuals composing the various member associations.

Funds are now being sought whereby some such activities can be underwritten as a definite start toward expansion. Admittedly, no disruptive change, far-reaching reorganization, or displacement of the Federation should be attempted but it should be recognized that changes are demanded and there should be whole-hearted, earnest endeavor to constantly push forward to the end that is sought, keeping the Federation always in a position to meet the changing needs of the growing field of sewerage and sewage treatment.

The Committee feels that changes in the Constitution and By-Laws of the Federation should be made to eliminate features which work to limit the activities of the organization to those of the member associations and which prevent the formation of a central organization needed to coordinate and expand activities. Such changes cannot be made at this annual meeting, but it is recommended that an active committee be put to work to formulate such changes and report to the Executive Committee within ninety days, and after approval of that committee, revisions be placed before a special meeting of the Board of Control.

FEDERATION BOARD OF CONTROL ANNUAL MEETING

Further discussion of the Report at the meeting of the Board of Control resulted in passage of a resolution that the first national meeting of the Federation be held within a year in conjunction with the meeting of a member association of the Federation. (Note. This does not refer to the meeting of the New Jersey Sewage Works Association on March 20–22, 1940, as this Association is not a member of the Federation.) A Committee will be appointed by Mr. Emerson to arrange for the time and place of the national meeting of the Federation.

The complete minutes of the meeting of the Board of Control will be published, as usual, in the March issue. These notes have been preprinted in order to acquaint all readers of THIS JOURNAL, as promptly as possible, with the important developments in the history of the Federation that are likely to occur in 1940.

Further information on the present status and projected plans of the Federation was given in a statement presented by Mr. Emerson to the New York State Sewage Works Association on January 19, 1940. This statement follows:

FEDERATION OF SEWAGE WORKS ASSOCIATIONS

By CHAS. A. EMERSON, Chairman *

At the Annual Meeting of the Board of Control of the Federation held yesterday afternoon, I was instructed to present to you the felicitations of the Board and best wishes for your continued growth and prosperity.

You will, I know, be interested in learning that the Federation has had a good year. On December 31, the twenty-five affiliated associations in this country, Canada, England, and the Argentine, had a total membership of 2,744 —an all-time peak. In addition, there were 413 individual subscribers to SEWAGE WORKS JOURNAL residing in this and some thirty foreign countries. It can safely be said that the Federation is the largest association of sewage workers in the world, and also that no professional journal other than SEWAGE WORKS JOURNAL has a subscription list of over 3,000 individuals primarily interested in sewage treatment.

You will also be interested in learning that over 1,700 copies of the volume issued by the Federation a little over a year ago, entitled "MODERN SEWAGE DISPOSAL," have been sold. The demand for the book continues and it has received many favorable comments.

While the Federation has gone a long way and has been of real service in the field of sewerage and sewage treatment during the past eleven years, a

* Delivered at the Luncheon Meeting of the New York State Sewage Works Association, January 19, 1940.

considerable number of our oldest members and staunchest supporters have felt for some time that our present type of organization, consisting primarily of separate groups of workers scattered throughout the country, bound together only through the medium of SEWAGE WORKS JOURNAL, and the part-time efforts of volunteer officers, can never hope to adequately meet the needs of the workers in this rapidly growing and ever changing field, nor can it truly represent them.

This and similar criticisms and suggestions have been discussed at length in meetings of the Executive Committee and the Board of Control. A special committee has been studying the whole problem and yesterday submitted a preliminary report which was accepted by the Board and the committee was directed to continue its studies and submit a final report promptly. The Board also authorized a committee to investigate the feasibility of a national convention to be held within a year. I think it is fitting that I should give you a brief statement of some of these matters, as you were one of the earliest affiliates of the Federation, and through your interest and the wise guidance of a succession of capable officers, have now become the largest state sewage works association and constitute about twenty-five per cent of the members of the Federation resident in the United States.

Recently there has been apparent an increasing demand for a national sewerage association which would serve the field of sewerage and sewage treatment in a comprehensive manner. There have also been suggestions that as the waterworks and sewerage fields are closely allied, the best interests of all would be served by a combined association.

It is true that waterworks and sewerage are divisions of the great field of sanitary science, working side by side for the protection of public health, and that both depend upon the same fundamental laws of hydraulics, chemistry and biology, and also that many of the materials and items of equipment employed in water supply and water purification are similar to or identical with those used in sewage collection and sewage treatment. It is also true that there are numerous points in common between sewerage and sewage treatment engineering and branches of municipal engineering other than waterworks.

An indication that some method of measurement other than the extent of duplication of engineering principles must be given consideration is shown by the fact that a comparison of our membership lists with those of other organizations in the general fields of sanitary science and public work shows comparatively little duplication of membership.

The Board of Control, after careful consideration, feels that we should continue as a separate organization and strive for development and expansion rather than for combination or consolidation with some other organization.

It is true that a nationally organized, centrally controlled association has advantages in certain directions which are not possessed by our present Federation, but it is also true that these large centralized organizations have generally found it advisable to also develop, or perhaps I should say permit, comparatively small sections or groups of members, analogous to our state associations, wherein the various problems of a particular district may be discussed at local meetings which the members may attend at reasonable cost and with a minimum loss of time.

To summarize: The problems now facing the Board are how best to combine numerous divergent viewpoints and adjust our organization so that there may be closer cooperation between the member associations; that the general officers and the representatives of the member associations may have better and more effective contact; that SEWAGE WORKS JOURNAL may be increased in size and usefulness; and that there may be some centralized guidance to further the efforts of the member associations, stimulate committee work, standardize procedure, and provide a common meeting ground for the widest possible interchange of views.

To do all of these things will take time, but a start has been made. There still remains some difference in opinion, but on one point all members of the Board agree—namely, that nothing is to be done which will jeopardize the progress already made by the member associations or lessen any advantage inherent to the present organization. All are determined that such changes as are to be adopted must be well considered and must pave the way for future growth and increasing strength and usefulness. We are starting on this program of expansion with the largest organization of its kind in the world, and surely more can be accomplished by building upon this foundation than by launching some other organization to face obstacles which we have solved through years of effort.

Editorial

SEWAGE TREATMENT IN LARGE AMERICAN CITIES

The differences between partial and so-called complete treatment of sewage are clearly understood by sewage chemists and sanitary engineers, but to the general public a sewage treatment plant is usually a "reduction plant," and the differences between sedimentation and activated sludge treatment are quite vague. This is understandable because, even among sewage chemists and engineers, there seems to be less emphasis on the high efficiency of activated sludge treatment than during the earlier years of its development. Scum removal, heating of sludge, control of digestion, utilization of gas, and incineration of sludge now receive most attention in the literature and in the design of new works, although none of these necessary adjuncts to sedimentation tanks contributes anything toward further efficiency of treatment.

The addition of further treatment, usually by chemicals or activated sludge, following sedimentation, is the important difference that should be emphasized in comparing the sewage treatment facilities of various cities. The results of various gradations of treatment are best expressed by the removal of biochemical oxygen demand, particularly with reference to the assimilative capacity of the stream or lake into which the effluent is discharged. Likewise the costs of construction and operation are correlated with the degree of removal of B.O.D., although not in direct ratio to the per cent removal. It is usually assumed that plain settling will remove from 35 to 45 per cent of the B.O.D., chemical treatment 60 to 70 per cent, and activated sludge 90 per cent. The difference between 35 and 90 per cent is of great significance, and activated sludge treatment should accordingly be rated far above plain sedimentation in a comparison of treatment projects.

This does not mean that installation of sedimentation only is a confession of inadequate treatment, for if the conditions of dilution are adequate, or if chlorination is used to obtain bactericidal efficiency, a plain sedimentation plant, as at Detroit or Buffalo, may meet the needs of the situation as satisfactorily as an activated sludge plant at Chicago or Columbus. Nevertheless, Chicago and Columbus should be given credit for the more complete and expensive plants they have had to construct and operate.

Another factor that should be recognized is that, no matter how efficient the process, the overall degree of treatment for a complete project decreases if all of the sewage is not intercepted and treated. Likewise, stormwater overflow lowers the net average degree of treatment for all projects. For these reasons a project can hardly exceed an overall degree of purification of 85 per cent, even though the activated sludge plant may produce 90 to 95 per cent reduction of B.O.D.

The largest cities in America differ profoundly in the degree of treatment provided, and some rather surprising results appear when a list is made to show the overall degree of treatment. The following table shows the estimated percentage treatment for some twenty-five of the largest cities of America. The estimates are not claimed to be precise, and are subject to some revision as to relative order of distribution, but they are probably close enough to show the effective population treated at each of the cities within reasonable limits, and also the great excess of effective treatment at Chicago, over any other city in America and, most likely, in the world. A decade ago, The Sanitary District of Chicago was berated for delay in installing sewage treatment works, but such criticism at the present time is ill-advised.

ESTIMATE OF DEGREE OF TREATMENT OF SEWAGE BASED ON REDUCTION OF B.O.D. FOR ENTIRE PROJECT
January 1940

City	Per Cent Treatment	Population	Effective Population Treated
Milwaukee	85	780,000	663,000
Cleveland	75	1,200,000	900,000
Columbus	75	320,000	240,000
Indianapolis	75	420,000	315,000
Chicago	70	4,400,000	3,080,000
Baltimore	70	750,000	525,000
Minneapolis-St. Paul	40	700,000	280,000
Washington, D. C.	35	550,000	192,000
Buffalo	30	600,000	180,000
Denver	30	280,000	84,000
Toledo	30	300,000	90,000
New York	25	8,100,000	2,025,000
Philadelphia	15	2,000,000	300,000
Toronto	15	700,000	105,000
San Francisco	10	780,000	78,000
Seattle	10	400,000	40,000
Los Angeles	5	1,300,000	65,000
Detroit	0	1,600,000	0
Boston	0	2,000,000	0
Pittsburgh	0	750,000	0
Cincinnati	0	500,000	0
Duluth	0	115,000	0
Portland	0	300,000	0
Kansas City	0	450,000	0
St. Louis	−20	950,000	0

Some explanatory notes are essential to amplify the tabulated data.

Milwaukee has one activated sludge plant, recently enlarged to include outlying villages. Milwaukee is a densely-populated city and the project, as a whole, shows about the maximum overall degree of treatment that can be expected in a large city.

Cleveland has the Easterly activated sludge plant, the Westerly Imhoff plant, and the Southerly trickling filter plant.

Columbus has recently completed an activated sludge plant that replaces an old trickling filter.

Indianapolis operates with plain aeration during the winter and activated sludge in the summer.

Chicago (The Sanitary District) has not yet put the Southwest Treatment Works in full operation, but when it is in complete operation this year, the overall percentage efficiency of the District will reach if not exceed that of Milwaukee, and the population effectively treated will likewise increase proportionately. Two activated sludge plants, the North Side and the Southwest, are now treating, each, more sewage than any other activated sludge plant in the world. In addition, there is the third activated sludge plant, the Calumet, and the West Side Imhoff plant.

Baltimore has added activated sludge treatment as an adjunct to the 30-year old trickling filters, but the new plant is only now ready for operation.

Minneapolis-St. Paul can increase the 40 per cent efficiency by bringing more sewage to the plant and using chemicals for greater B.O.D. reduction but, so far, chemicals have not been used.

Washington has enough dilution in the Potomac River to get along for the present with clarification.

Buffalo has a fine, new plant in which chlorination is of paramount importance, for protection of water supplies downstream at Tonawanda and Niagara Falls. The great dilution in the Niagara River makes it unnecessary for Buffalo to accomplish a high percentage removal of B.O.D.

Denver has had a low flow, compared with the design, and chemicals have not been used. (It seems as though we must wait a long time to get data from the new, large, chemical precipitation plants.)

Toledo has only primary treatment and chlorination.

New York City is now operating the Ward's Island and Tallmans Island activated sludge plants and the Coney Island chemical precipitation plant. These account for only about one-fourth effective treatment of the huge population of 8,100,000.

Philadelphia is operating only one large Imhoff plant, the ancient Northeasterly Works, plus a small trickling filter at Pennypack Creek.

Toronto has just voted to construct a modern sedimentation plant. The relatively small North Toronto activated sludge plant is now in operation, plus the obsolete lake-front clarification works.

San Francisco has one small activated sludge plant in the Golden Gate, and a new sedimentation plant (with flocculation) at Richmond-Sunset. A commission has just been appointed to report on sewage treatment for the populous East Bay cities.

Seattle has recently put into service an 8 m.g.d. clarification plant for part of the city.

Los Angeles has only fine-screening at Hyperion, and disposal in the ocean. The County Sanitation District, surrounding the City of Los Angeles, has installed clarification works.

Detroit is completing the largest sedimentation plant in America, designed for 2,400,000 people, but at present no sewage is being treated. The effective treatment at capacity operation will not exceed 800,000.

Boston has no treatment, but has just decided to have plans prepared for a sedimentation plant for the South Metropolitan District.

Pittsburgh and Cincinnati have no treatment although a small plant is now under construction at the latter city.

Duluth has voted to go ahead with sedimentation and chlorination.

Portland has had reports but no sewage treatment. Kansas City has no treatment. St. Louis not only has no treatment, but actually increases the pollution of the Mississippi River by grinding its garbage and dumping it into the river. Therefore, St. Louis now rates sub-zero in sewage treatment.

The surprising thing about this comparison is the few cities that have installed more than 50 per cent treatment, and also the thirteen, out of twenty-five, that have only 15 per cent, or less, effective treatment. It looks as though there is still a large field for installation of sewage treatment works.

F. W. Mohlman

Proceedings of Local Associations

NORTH DAKOTA WATER AND SEWAGE WORKS CONFERENCE HOLDS ELEVENTH ANNUAL MEETING

Dickinson, North Dakota, September 22–23, 1939

"Ride 'em, cowboy" was the password at the eleventh annual meeting of the North Dakota Water and Sewage Works Conference held at Dickinson, North Dakota, on Friday and Saturday, September 22 and 23. Situated at the edge of the Badlands and the dude ranching area, this typical western town mixed plenty of western hospitality with the business of the day. Official registrants numbered 95.

President Bill Yegen called the meeting to order on Friday morning and delivered a fine address on the work of the Conference during the past year. He mentioned the appointment of committees to work out a plan for the licensing and certification of operators and to study the cause of the failure of asphalt-containing jointing compounds. He also discussed the pioneering work in water treatment practices in North Dakota, in the use of activated carbon, sodium aluminate, catalyzers, high chlorine residuals, etc.

Following the president's address, a business session was held during which committee reports were presented and new committees appointed.

J. Arthur Jensen, president, A. W. W. A., was the main speaker at the luncheon session on Friday. Others in attendance at this luncheon were Maysil N. Williams, M.D., state health officer, State Department of Health; Frank R. Shaw, senior sanitary engineer, U. S. Public Health Service, Chicago; W. W. Towne, state sanitary engineer, and R. E. Spieker, county sanitary engineer, South Dakota State Department of Health; Arnold Nesheim, sanitary engineer, U. S. Indian Service, Billings, Montana; Claude Eyer, city engineer, Glendive, Montana; and official representatives of local state agencies.

Following the afternoon meeting, which adjourned at 3:30, the group drove to Buddy's ranch in the heart of the Badlands to witness a wild-west rodeo and bucking contest. Following this, they enjoyed a typical western supper to the ranch house, consisting of barbecued beef, beans, rice pudding, and all the trimmings

Papers were heard on Saturday and in the afternoon several hours were devoted to a round-table discussion of questions placed in the question box. A tour of inspection of the new Dickinson sewage treatment plant and the city water works followed by a Dutch lunch at the Country Club and the drawing of a watch supplied by one of the corporate memberships and presented by President Jensen completed the meeting.

A post-convention tour of the Badlands left Dickinson on Sunday morning and ended at the Custer Trail Dude Ranch for dinner at which 35 were present.

Officers elected for 1940 were: William J. Nordley, Edgeley, *President;* George G. Doorley, Bismarck, *Vice-President;* Lloyd K. Clark, Bismarck, *Secretary-Treasurer.* New directors are William Yegen, Bismarck, and C. S. Childs, Minneapolis. Wahpeton was selected as the 1940 convention city.

Among the papers presented during the conference sessions were the following:

Lawrence H. Kirk of the Flox Company presented a brief but interesting and valuable paper on the application of polyphosphates to municipal water supplies.

F. O. Malloy of the F. O. Malloy Company, Edgeley, North Dakota, described the metallizing process for protection of metal surfaces in water works and sewage plants by the use of noncorrodible metals. By this process a monolithic coating of lead, copper, zinc, nickel, aluminum, etc., can be placed on the inside of a water tank or wash water trough, on digester or clarifier mechanisms, sewage and water plant superstructures, or any other metal exposed to corrosive action. The choice of metal to be used depends upon the condition to which it is subjected. A fusing action maintains the bond to the surface of the structural metal.

Whether one is employing metallizing or painting to prevent corrosion, sandblasting is strongly recommended as the only effective method of thoroughly removing all old paint, scale, etc. Unless this is done, the job is a waste of money.

Mr. Malloy stated that where sandblasting is employed to prepare the surface properly, a metallizing job can be done at about 60 per cent above the entire cost of a paint job. He uses steel filings in his sandblasting to prevent injury to metal surfaces, sand being too hard thus cutting too fast.

Cathodic Protection for Water Works Equipment, by W. D. Loreau, superintendent of water works, Dundee, Michigan, was presented by R. G. Ball, Chicago.

E. L. Lium, consulting engineer, Grand Forks, presented a discussion on the American Water Works Association pipe-laying standards.

L. K. Clark, state sanitary engineer, cited personally conducted experiments on the bacterial content of jute, in which he found jute containing excessive bacterial contamination. He also mentioned the various methods of sterilizing jute, stating that in his experiments sterilization by steam pressure and by hot air were very effective. Sterilization in a chlorine solution was the least effective in reducing the bacteria content.

The sound picture "Pipe and the Public Welfare" furnished by the Cast Iron Pipe Research Association, was shown. Members expressed considerable interest in this film, especially in that portion which showed the testing of pipe.

A paper, "Motor Maintenance and Repair," prepared by Harry Lundquist of the Neptune Meter Company, was read by A. Rasmussen of the same company.

In discussing "The Practical Application of Sanitary Standards," Lloyd K. Clark, state sanitary engineer, Bismarck, pointed out the public health significance of different types of equipent and installations.

Among the papers presented during the conference sessions were the following: "Experiences Installing a Sewerage System in Rock and Quicksand" by R. F. Mirick, construction engineer at Killdeer, brought out many interesting incidents, some of them quite humorous. The men on his crew have been working in so much water and quicksand they're beginning to grow web feet, he stated. Mr. Mirick described some of the difficulties encountered during the construction of a sewerage system and Imhoff tank at Killdeer due to the presence of rock and quicksand.

W. W. Towne, South Dakota state sanitary engineer, spoke on "What is the Strength of Your Sewage?" He discussed the various types of sewage treatment using lantern slide projections for illustration. Graphs were shown depicting the percentage of B.O.D. and total solids removal for different periods of retention. He also discussed the process of sludge digestion of both seeded and unseeded sludge. Various tests for the determination of strength were listed, and he cautioned against placing too much reliance on the methylene blue reduction test.

Gilbert Groff, chemical engineer, State Department of Health, presented an interesting discussion on what happens to polluted streams under ice coverage.

In discussing "The Practical Application of Sanitary Standards," Lloyd K. Clark, state sanitary engineer, pointed out the dangers of cross-connecting city water supplies to equipment in sewage plants such as chlorinators, sludge flushing devices, sewage pump priming, etc. He mentioned the need for addition treatment of sewage where only primary treatment was provided. Elimination of the practice of dumping raw and partially treated sewage into streams was also discussed.

LLOYD K. CLARK, *Secretary*

PACIFIC NORTHWEST SEWAGE WORKS ASSOCIATION

Second Annual Short Course, University of Idaho, Moscow, Idaho, November 2–4, 1939

The second annual Short Course for Water Works and Sewage Treatment Operators, with double the number attending as was anticipated, met at the University of Idaho at Moscow, November 2, 3 and 4. The 125 operators and technicians came from the entire Northwest, many coming as far as 650 miles to attend the School.

At the first morning session Dr. H. L. McMartin, Director, Idaho State Division of Public Health, stressed the "Relationship Between

Water and Sewage Plant Operation and Public Health," and asserted that the sanitary engineers, although generally unknown and unseen, have played a "major world role in reducing the death rate."

The dangers of "the erroneous idea" that streams are "self-purifying within so many feet or so many miles" was forcefully brought to the operators by Roy W. Harris, Chief Public Health Engineer of Washington, in his paper "Protecting Watersheds and Surface Supplies." He outlined the legal phases connected with the protection of municipal watersheds.

The part chlorination plants have played in safeguarding city water systems was described by Carl E. Green, Oregon State Sanitary Engineer. He credited the use of chlorine largely for the reduction of the national typhoid death rate from 35 per 1000 to four per 1000. There are over 7000 communities now using chlorination. His practical as well as technical discussion brought many questions from individual operators.

A field trip to the recently completed trickling filter sewage plant of Moscow and the waterworks at Lewiston featured the Friday afternoon session. The inspection of the waterworks at Lewiston was followed by a banquet at the Lewis and Clark Hotel and a movie in technicolor of the history of Lewiston's tap water produced and directed by Lewiston's well known City Engineer, "Bill" Hughes.

One of the highlights of the meeting came Saturday morning when the entire group was divided into three sections and actual demonstrations of the various control tests were shown to the operators. The questions asked during these demonstrations and at the "Round Table Discussions" certainly showed that the operators were eager to learn more about their profession.

Other speakers during the three days were: Dr. W. V. Halverson, University of Idaho bacteriologist; W. V. Leonard, State Sanitary Engineer of Idaho; Alex Lindsay, Spokane Water Plant Superintendent; Glen W. Campbell, Bellingham City Chemist and Bacteriologist; R. B. Van Horn, Civil Engineering Head, University of Washington; E. A. Heiss, Wallace and Tiernan, Seattle; Earl M. Kelly, Dorr Company, Inc., Los Angeles; H. C. Clare, Assistant Idaho Sanitary Engineer; and Paul E. Seufer, Assistant Public Health Engineer, State of Washington. Professor I. N. Carter was in charge of the School being chairman of the Idaho Sub-Committee of the A. W. W. A. on Short Courses. "Mike" Leonard and "Bill" Hughes assisted him in the arrangements. The Short Course is sponsored by the Pacific Northwest Section of the American Waterworks Association. The third annual school will be held next year at Oregon State College at Corvallis.

Reviews and Abstracts

CITY OF MANCHESTER ANNUAL REPORT OF RIVERS DEPARTMENT FOR THE YEAR ENDING MARCH 31, 1939

(A pamphlet of 83 pages, plus 7 tables and 2 diagrams)

The Rivers Committee is concerned with the disposal of the city sewage and the control of trade effluents. Its total expenditures for the year ending March 31, 1939, were £219,658 11s. 11d. ($878,634). Under the Public Health (Drainage of Trade Premises) Act, 1937, a scale of trade effluent service has been adopted which varies from 2d. to 4d. per 1,000 Imp. gal. (2.8 to 5.6 cents per 1,000 U. S. gal.), to be charged in cases where the trader is unable to demonstrate that he holds under the Act a prescriptive right to discharge trade effluent to the sewer. In all cases where the volume of discharge does not exceed 1,000 Imp. gal. per day, a standard charge is made of £1 (now $4.00) per annum.

The River Committee operates six sewage treatment works, at Withington, Davyhulme, Northenden, Moss Side, Middleton, and Heyhead.

The Withington plant serves about 47,000 population, with an average daily flow of 1,838,000 Imp. gal. (2,205,600 U. S. gal.) daily or 39 Imp. gal. (46.8 U. S. gal.) per capita. It includes sedimentation with double contact beds, Imhoff tanks, and activated sludge. At present 59 per cent of the flow is treated by activated sludge, after preliminary settling for 40 min. dry weather flow (D. W. F.). The detention period is 5 hours in the smaller unit and 5.8 hours in the larger, the air used being 1.52 cu. ft. and 1.32 cu. ft. per Imp. gal. (1.27 and 1.10 cu. ft. per U. S. gal.) respectively. The effluents show a B.O.D. from 10.0 to 15.2 p.p.m. and suspended solids 11 p.p.m. The activated sludge effluent in part is passed through the contact beds.

The Davyhulme plant serves about 810,000 population, with an average daily flow of 59,290,000 Imp. gal. (71,148,000 U. S. gal.) or 59 Imp. gal. (70.8 U. S. gal.) per capita. All the sewage passes through detritus tanks. About 45 per cent of the settled flow is treated by activated sludge. The primary and secondary contact beds are still in use for the balance of the flow. About half of the sludge is carried out to sea by two steamers. Sludge digestion is being studied.

Appended to the report is a general commentary on the practical inauguration of the Public Health (Drainage of Trade Premises) Act, 1937, by William Porthouse, Secretary of the Manchester Corporation Rivers Department (Cf. Institute of Sewage Purification, July, 1939). Briefly, the Act defines a "trade effluent" as "any liquid either with or without particles of matter in suspension therein, which is wholly or in part produced in the course of any trade or industry carried on at trade premises." Only laundering liquors are exempted.

The Act distinguishes between cases in which the consent of the local authority is necessary to discharge trade effluent into a sewer and where such consent is not necessary (in general for those who exercised a right of discharge to the sewers during the twelve months ending March 3, 1937). The right to discharge is, however, restricted to the particular premises and sewer.

The intent of the Act is to limit the number of points of discharge and to concentrate the discharge for treatment by local authorities. The trader has the right, if he so elects, to treat his effluent himself.

The British authorities are somewhat perplexed by the Act. Only one authority has adopted by-laws, although the Act has been in force nearly a year. The Act requires the trader to serve a "Trade Effluent Notice" on the local authority. A consent is best given by statutory form, with a schedule of prohibitions and limitations.

The acquiring of a prescriptive right has occasioned difficulty, since it discriminates between recent and old users. The determination of flow by the trader is likely to be inaccurate and may be set at a minimum. Mr. Porthouse recommends that all users be admitted to the sewers on the same conditions as far as charges go.

The rights inherent to "trade premises" are in question, also, as some new buildings since the passage of the Act are claimed by owners to be covered by the prescriptive right.

The right to charge "traders" for service is welcomed, but the amount of charge is hard to determine. Halifax has charged from 1.44 to 4.8 pence per 1,000 Imp. gal. (2 to 6.7 cents per 1,000 U. S. gal.). Huddersfield has a flat rate of 2 pence with 4 pence for non-rate payers (2.8 and 5.6 cents per 1,000 U. S. gal.). Bradford charges from 1 to 6 pence (1.4 to 8.3 cents per 1,000 U. S. gal.). A flat rate is not entirely equitable, because of variations in strength and solids. Manchester is considering a scale roughly of "A" effluents, 2 pence per 1,000 Imp. gal. (2.8 cents per 1,000 U. S. gal.) for textile industry discharges; "B" effluents, 3 pence per 1,000 Imp. gal. (4.2 cents per 1,000 U. S. gal.) for chemical industry discharges; and "C" effluents, 4 pence per 1,000 Imp. gal. (5.6 cents per 1,000 U. S. gal.) for effluents from gas works or those containing excessive amounts of organic matter. The right is reserved to make special charges, where required, on the merits of the case.

The Turton Urban District council has published by-laws, which were modified after criticism by traders. These contain a sliding scale. Trade effluents with an oxygen absorbed value not exceeding 100 parts per million are charged at ½ pence per 1,000 Imp. gal. (0.83 cents per 1,000 U. S. gal.); others as follows:

Range Parts per Million	Charge Pence per 1,000 Imp. Gal.	Cents per 1,000 U. S. Gal.
110 to 250	1	1.4
260 to 500	3	4.2
510 to 1000	6	8.4

The charge for effluents over 1,000 p.p.m. is subject to special agreement. The oxygen absorption is to be based on the maximum figure for any one sample taken during any quarter.

In Manchester special agreements have been entered into with 89 traders, but not always for trade wastes. Where the discharge is less than 1,000 Imp. gal. (1,200 U. S. gal.) per day, a flat rate of One Pound ($4.00) is charged per annum.

On the other hand Coventry has arranged free access for volumes up to 2,500 Imp. gal. (3,000 U. S. gal.) per day, after which for discharges exceeding 200,000 Imp. gal. (240,000 U. S. gal.) per quarter, but not over 500,000 Imp. gal. (600,000 U. S. gal.), a flat rate of one penny per 1,000 Imp. gal. (1.4 cents per 1,000 U. S. gal.) is charged.

The charge should have a reasonable relation to the actual cost of the service to the local authority, including the entire cost of sewage treatment plus the use of sewers, with overhead, interest, depreciation, etc., added. A final cost should not be less than one-half penny per 1,000 Imp. gal. (0.7 cents per 1,000 U. S. gal.).

Sheffield, however, has eliminated charges.

Roof and surface water and domestic drainage are exempt, as well as condensing water.

Harmful matters such as solids in suspension, grease, oil, sugar, tar or tar oil and cyanides are to be eliminated, as far as practicable. In Manchester, in addition, petrol and other inflammable light oils, carbide of calcium, carbon disulfide, sulfides, hydrosulfides and polysulfides are banned. Probably chromates will also be barred.

Condensing water is admitted to sewers.

Permissible upper limits are suggested, as follows:

Determination	Limits in Manchester			Elsewhere		
	Grains per Imp. Gal.	P.p.m.	pH	Grains per Imp. Gal.	P.p.m.	pH
Suspended Solids	30	428	—	20–30	285–428	—
Grease and Oil	30	428	5–12	—	—	6–10
Cyanides	0	0	—	3.5	50	—
Yeast and Sugar	30	428	—	—	—	—
Sugar	35–70	500–1000	—	14–35	200–500	—
pH			5–12			7–10

The recording of the volume of discharge is desirable. There is doubt if the trader is to assume the entire expense. Too much detail and expense in collecting data may absorb the receipts. The cost of suitable measuring and recording devices is considerable. Maybe the municipality should install the meters and make a charge therefor. Inspection chambers must be provided. All associated authorities which deliver sewage to Manchester are required to adopt its by-laws. The local authority has power to control the rate of discharge by a trader.

Garages are treated as domestic garages and exempt, unless connected with the transport industry. Laundries are exempt, although their discharge is hot and foul. The classification of dyeing and cleaning effluents is in debate.

In Manchester all building plans are passed on by the Rivers Department. Other details of administration are discussed.

Mr. Porthouse believes that the Act may engender some friction between local authorities and traders; is unnecessarily involved; and needs revision, particularly by eliminating the principle of prescriptive right.

Various typical forms are appended.

Note.—Conversion from Pounds sterling to dollars is based on the approximate current exchange basis (Dec. 1939) of £1 = $4.00.

See also—Contractor's Record and Municipal Engineering, Paper, **50**, 911–915 (1939). Discussion, **50**, 931–2, 934, 947–8. *Also—The Surveyor,* Paper, July 25, 1939. Discussion, **96**, 209–211 (1939).

In the discussion, Mr. Porthouse indicated that the Act was unsatisfactory, unfair in some respects and impossible to administer economically and efficiently. However, it was a definite and welcome step in the right direction.

Mr. A. R. Ward, of Stockport, thought the prescriptive rights were unfairly set up. He criticized the exemption of laundry wastes, because in one small town the laundry waste was greater than the domestic sewage. Gas liquor could be dealt with only in concentrations of about 0.5 per cent. He preferred acidity and alkalinity determinations to pH, and had suggested 2,000 p.p.m. acidity or alkalinity for Stockport.

Mr. C. B. Townend, of West Middlesex, said his board was convinced that all manufacturers should pay at cost for special service, or a sliding scale. The formula worked out roughly on a basis of $1 + M/75 + S/60$ in pence per 1,000 Imp. gal. (1.67 cents per 1,000 U. S. gal.) where M = McGowan figure * of the trade waste after settling and S was the figure for suspended solids in parts per 100,000. For normal sewage the cost was 2½ pence per 1,000 Imp. gal. (3.4 cents per 1,000 U. S. gal.). The cost is divided at most works between—

(1) preliminary treatment, including pumping, screening, grit removal, sedimentation and miscellaneous, all more or less proportional to volume.
(2) biological treatment, not only proportional to volume but to strength.
(3) sludge disposal, proportional to the amount of sludge forming material present.

* The McGowan figure is computed as follows, with results in parts per 100,000: (Ammonia plus org. N) 4.5 + (4-hour Ox. absorbed) 6.5.

In general, on small situations sampling once or twice a year sufficed. For the large situations, automatic sampling may be desirable.

A sliding scale gives credit to the manufacturer who reduces the waste discharged. Mr. Townend considered it more practical than setting fixed limits to be met. Hence at West Middlesex each case is on its own merits, with the costing formula to regulate the situation. He also concurred in objecting to prescriptive rights.

Mr. J. Hurley, of Wolverhampton, concurred in objecting to the exemption of laundries. He pointed out that under the Townend formula a charge of 1 penny per 1,000 Imp. gal. (1.4 cents per 1,000 U. S. gal.) would be made for clean water, thus reflecting the effect of volume.

Mr. W. T. Lockett, of West Middlesex, doubted if dilution of effluents was likely to be troublesome on small situations. If abused, the Act gave powers to correct. The quantity discharged could be limited by orifices or other devices. As to standards or limits for various non-inhibitory constituents, he felt that where the charge was low the regulations should be rather stringent, whereas with a charge approximating the cost of treatment less stringent regulations should apply. Where the charge was practically the cost, easy limits might be adopted. With the wastes present in West Middlesex, the Townend formula was decidedly appropriate.

Mr. E. H. Arrowsmith, of Bredbury and Romiley, cited a case where the manufacturer desired to discharge a volume large enough to exhaust the capacity of a local sewer. When informed of the cost, other means of outlet were found. At Bredbury the sewage had a suspended solids figure of 1,500 to 1,600 p.p.m. because of wastes from a wall paper factory. This waste was promptly settled prior to discharge, since the Act went into force. He recommended quarterly readings on trade effluent meters. He concurred that laundry wastes should not be exempt.

Mr. R. Hicks, of Gravesend, cited cases recently decided which held that wastes prejudicially affecting the treatment of sewage were unlawful for discharge to a sewer. Two points require clarification: (1) as to dilution, its meaning and permissibility; (2) as to the amount of trade waste a sewage works can handle, dependent on the requisite quality of effluent.

Dr. H. T. Calvert pointed out that under the Act the Ministry of Health had no discretionary powers on limits of permissible amounts for discharge. The by-laws may permit a certain volume of effluent to be discharged without any consent. All by-laws must be prefaced by two months publication of notice before adoption.

Mr. Porthouse in concluding agreed that the officers should advise their local boards on policies. He urged that prescriptive rights be destroyed. The Act did not validate unlawful acts prior to the Act, under any guise of prescriptive rights.

LANGDON PEARSE

THE SEWAGE TREATMENT PLANT AT LEIDEN (NETHERLANDS)

BY D. BOOGERD

Publieke Werken, 8, 51 (April, 1939)

Leiden has about 33,000 inhabitants with a dry weather sewage flow of 1.6 m.g.d. The plant consists of a distribution chamber, eight Dortmund tanks for pre-settling, with an average detention period of 16.5 hours and sludge storage capacity of 48 hours for concentration of sludge; separate sludge digestion tanks with a capacity of 2.25 cu. ft./cap., two trickling filters 60 ft. in diameter and 6 ft. deep filled with slag and equipped with rotary distributors, with a rate of 27 gallons per cu. yd. of filter material; a mechanically cleaned center feed humus tank, sludge drying beds, sludge pumps, office and laboratory. The four digestion units contain mixing and heating units (Kessener type) and are insulated with cork. All buildings and tanks are placed on piles 35 to 40 ft. deep. The bottom of the filters was constructed umbrella fashion, allowing rooms about 6 ft. high which can be used as bomb shelters in time of war. Filter loadings are 400 grams B.O.D. per cu. m. of filter material a day. Average results obtained in p.p.m. are:

	Settled Sewage	Final Effluent
	Parts per Million	
B.O.D.	250	40
Oxygen consumed	182.5	55
Ammonia	60	32.5
Nitrite (N_2O_3)	—	2.5
Nitrate (N_2O_5)	—	27.5

The volume of suspended solids in c.c. per liter is: raw sewage 3.5, settled 0.2, final effluent 0.1. Gas production averages 22,750 cu. ft. per day.

WILLEM RUDOLFS

SEWAGE TREATMENT AT HILVERSUM (NETHERLANDS)

BY J. F. GROOTE

Publieke Werken, 8, 14 (1939)

Hilversum has an unusually difficult problem in disposal of domestic and industrial wastes. The drainage is east and west, but on the east side no open water is available for discharge of effluents, all drainage being subterraneous. On the west side is a small canal capable of carrying storm water and highly purified sewage. No storm water overflows can be constructed, with the result that on a rainy day the flow increases from about 1.2 to 14.7 m.g.d. This water must seep away, since it is economically impossible to pump the water over a hill 60 ft. high. The old sand filters were a continuous source of nuisance and odors. Ponds for collection and seepage of storm water have been constructed and wherever possible a separate sewer system constructed.

The west side plant, which receives a dry weather sewage flow of about 1 m.g.d. with a B.O.D. of 400 to 700 p.p.m., consists of a Dorrco automatic screen, screenings shredders (the coarse material passing twice through the shredder), Dorr detritor, wet well and pumps, clarifier for pre-settling, round distribution chamber in the form of a funnel with upward flow and channels, activated sludge with Kessener aerators, final settling tanks, triple digestion, gas holder and sludge drying beds. The return sludge enters the aeration tanks at the inlet, but the settled sewage can enter at the inlet, one quarter or half way down the tank. The B.O.D. of the effluent varies between 7 and 10 p.p.m. (90 per cent reduction).

The primary and excess activated sludge runs into a pre-digester and is heated to 30–33° C., by the cooling water of the gas engines passing through a hollow stirring mechanism. The sludge then goes to a balloon-shaped digester for methane digestion, and finally to a third tank for after-digestion and concentration. The tanks are so well insulated that the temperature in the third tank remains at 25° C., although no heat is applied to the second and third tank. The gas produced is sufficient to produce power, heat and light for the entire installation. The buildings were designed by the famous modern architect Dudok. The slope of the digesters is planted with *Juniperus Pfitzeriana*, producing an unusually pleasing effect.

The plant Hilversum-East is under construction, and consists of screens, grit chambers, sandwashers, settling tanks, high rate trickling filters, secondary settling tanks and digesters. The final effluent is stored in a pond with a surface of about 8.75 acres to allow for seepage. The high rate filters are constructed on the basis of results obtained with large experimental units. The filter effluent is diluted by half with final effluent to obtain a surface filter rate of 3 cu. in. per sq. in. per hour.

The design of the plant was made by the city engineer in cooperation with the Government bureau of which Dr. Kessener is Director.

WILLEM RUDOLFS

REPORT OF BOARD OF REVIEW ON SEWAGE TREATMENT FOR CITY OF TORONTO

94 pp., September, 1939

This is a report to the Mayor and City Council of Toronto on sewage disposal. The majority report is signed by A. E. Berry, G. H. Ferguson, S. A. Greeley and C. W. Hubbell. A minority report is signed by W. B. Redfern. The majority report emphasizes the need for eliminating the present pollution of the waters of Lake Ontario used for water supply and bathing and recommends an activated sludge plant, with sludge disposal by digestion, mechanical dewatering and incineration. The location suggested is on Ashbridge's Bay. The proposed plant, designed to serve 700,000 population, with an average flow of 84 Imp. m.g.d. (100.8 U. S. m.g.d.), is estimated to cost $9,500,000, or $14.65 per capita for the present population of Toronto. The minority report recommends sedimentation tanks with effluent filters, sludge digestion, vacuum filters and chlorination at a cost of $5,474,000.

The report describes the local situation in great detail. The city covers 34 sq. mi. with a 10-mile water front on Lake Ontario. In 1938 it had a population of 647,803, of which 68,000 are served by the North Toronto sewage works. Outside of and adjacent to the city are 12 municipalities embracing 125,590 acres with a population of 210,814 (in 1938).

The water fronts are used extensively for bathing, recreation and commerce, as well as for sewage outlets. The lake level fluctuates about 4 feet. In the winter ice forms. The water supply is taken from Lake Ontario and filtered.

The city is sewered chiefly on the combined plan, with overflows at various points along the water front. Existing sewage works treat part of the sewage by sedimentation, with 3-hr. period, the effluent for the greater part going to the lake. A substantial amount of industrial wastes is expected, including some phenol waste. In the area of greater Toronto are seven sewage works.

Between 1909 and 1939, various reports have been made on sewage disposal and water treatment. These are briefly summarized. In 1933 a report by consulting engineers covered a site 12 mi. east of the present plant, with activated sludge treatment, the project to cost $20,428,000. In 1935, an activated sludge plant was recommended near the present works.

The water intakes are subject to surface and subsurface currents bringing pollution from the shore, coming from sewer outlets, storm drains and water courses. The chloride content of the water has increased from 8.1 p.p.m. in 1912 to 14.2 p.p.m. in 1938. An average of the record for 27 and 21 years, respectively, shows confirmed coliform bacteria of 282.9 and 225.1 per 1 c.c. at the two intakes, with maximum samples as high as 100,000 (none in last 7 years) and 10,000 occasionally. The pollution apparently moves in fields. In order to meet the U. S. Treasury standard for raw water, complete sewage treatment is required, with a relatively short outfall sewer.

The bathing beaches, located along the 10-mile water front, are well patronized during three summer months. The beach pollution often runs up to 100,000 coliform organisms per 100 c.c.

Storm overflows discharge along the water front, in amount estimated about 5 per cent of the annual volume of sewage. The effect is obscured by the discharge of partially settled sewage.

The proposed site is adjacent to the existing plant, in rather difficult soil conditions.

From 1925 to 1930, the annual average sewage flow was 119 Imp. gal. per capita per day (142.8 U. S. g.c.d.). The allowance for design was placed at 120 Imp. g.c.d. (144 U. S. g.c.d.) with maximum rates of 1.5 times for complete treatment and 2.5 times for sedimentation and chlorination. The sewage is strong, with a B.O.D. of 275 p.p.m. and suspended solids 275 p.p.m. (0.33 lb. per cap. per 24 hrs.).

Various treatment projects were discussed. Partial treatment with chlorination is estimated at $5,919,000 (including $4,171,000 for treatment). This covers an 84 Imp. m.g.d. plant with flocculation (0.5 hr.), preliminary sedimentation (2.0 hr.), effluent filters (1.87 Imp. g. per sq. ft. per min.) and sludge digestion (4 lb. per cu. ft. of tank per mo.).

Dewatering filters and incineration equipment are provided. The annual cost is estimated at $312,000, including a payroll of 70 men. Repairs and supplies are estimated at 1.25 per cent and fixed charges at 5.25 per cent. This plant is estimated to remove 75 per cent of suspended solids, 45 per cent of B.O.D. and 98 to 99.8 per cent of bacteria.

The activated sludge project was estimated in 1939 by the consulting engineers to cost $12,000,000 (including $8,385,000 for the treatment plant and $2,046,000 for preparation of site). This was originally based on an 84 Imp. m.g.d. capacity; preliminary sedimentation 2 hr.; aeration 5.5 hr. on mixed liquor; final sedimentation 520 Imp. gal. (624 U. S. gal.) per sq. ft. per 24 hr.; and sludge digestion, 2 lb. per cu. ft. per month. Digestion, followed by dewatering and dumping of cake, was recommended for the sludge disposal. The present board recommend incineration, and believe the entire activated sludge plant can be built for about $9,500,000, and operated for $515,000 per year, including pumping. The activated sludge plant is expected to remove 92 per cent of B.O.D. and suspended solids and 98 to 99.8 per cent of the bacteria.

The Board does not recommend either a chemical or biochemical treatment plant for Toronto conditions.

The minority report recommends partial treatment, and the omission of a relief high level intercepting sewer (proposed in 1935). Better utilization of dilution is stressed.

The report is of particular interest to those concerned with problems of sewage treatment and water supply around the Great Lakes.

LANGDON PEARSE

Addendum, Editor.—Mayor Day of Toronto proposed that the preliminary part of the plant be built for the present, leaving further treatment for future consideration. The present plant would cost $5,600,000 and the annual cost $590,625, of which $315,000 would be operating cost (*Canadian Engineer,* Nov. 28, 1939).

The proposed estimate does not include flocculation tanks, effluent filters or aeration tanks (plus final settling tanks). In the minority report flocculation tanks cost $879,000 and effluent filters $521,000. In the majority report aeration tanks cost $1,050,000 and final settling tanks $612,000. Instead of this equipment the Mayor's plan provides for sludge and digestion tanks to cost a total of $1,100,000 (*Canadian Engineer,* Dec. 5, 1939).

The Ontario Minister of Health advised the Toronto City Council that the Ontario Provincial Government would refuse to accept construction of a $5,600,000 plant as a solution of Toronto's problem. It would be approved only as the initial stage of a complete treatment plant. The remaining stage of the complete treatment plant must be constructed not later than four years subsequent to the first stage of the disposal works. The complete plant would cost $9,500,000 (*Canadian Engineer,* Dec. 12, 1939).

An election on Dec. 21, 1939, resulted in approval of the Mayor's plan.

NEW JERSEY COURT FINES VILLAGE AND COUNCILMEN FOR FAILURE TO BUILD SEWAGE TREATMENT WORKS

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WEST WILDWOOD SEWAGE PLANT

Adjudged guilty of contempt of court, the community of West Wildwood and its governing officials have been ordered by Vice Chancellor W. F. Sooy to comply with an order of the State Department of Health, issued five years ago, for the installation of a $35,000 sewage plant.

Failure of the municipality to observe the Health Board's order resulted in Court of Chancery proceedings. After obtaining an injunction against West Wildwood, the Attorney General, as counsel for the Health Board, brought contempt proceedings, which, at the direction of the Vice Chancellor, were directed to be criminal rather than civil, for failure to comply with the terms of the injunction, for the new sewage disposal plant.

The Vice Chancellor on August 22 imposed a penalty of $250 against the municipality and fines of $50 each on five present or former borough councilmen. George S. Fisher,

Benjamin Hann, Edward Strobel, J. Robert Hentges, Jr., and Harry Myers were the councilmen penalized. Commenting upon the officials' claim that financial embarrassment precluded compliance with the court order, Vice Chancellor Sooy said: "Compliance must be had even though the borough council confess to bankruptcy and turn over its government to the officers of the State as provided by statute." The Vice Chancellor found the municipality itself guilty of contempt on the theory citizens are responsible for the behavior of their elected representatives.

Court's Comment

"The borough or the taxpayers are responsible for the acts of its councilmen and cannot escape because the councilmen did not do their duty."

The power of the Court of Chancery to impose penalties for violation of its orders regarding public safety matters is virtually unlimited. Vice Chancellor Sooy said he "couldn't put a municipality in jail," but that he could fine its taxpayers $1,000,000 and could sentence each offending councilman to 100 years in jail.

West Wildwood officials have contended all along they wanted to build the sewage disposal plant but didn't have the money.

Finding themselves suddenly in the minority, two Democratic councilmen, Myers and Hentges, boycotted borough council meetings for eight weeks before they resigned June 20. By doing so, they left the three Republicans without a legal quorum to conduct municipal affairs.

Previously, Vice Chancellor Sooy remarked he didn't see how the three Republicans could be blamed for the situation, later commenting:

"As for Fisher, Hann and Strobel, they made only feeble efforts to comply with the court's order. With the decree staring them in the face and the community endangered by an unhealthy condition, they did nothing but try to sell a bond issue when the probability was there would be no buyers. All that was done in 1939 was to apply for a WPA grant."

The jurist then excoriated Myers and Hentges for refusal to attend regular council meetings "in order to satisfy some political desires." Their lawyer, J. Victor D'Aloia of Newark, then leaped up to defend his clients by asserting they acted on "advice of counsel," but the jurist replied:

"The advice of counsel does no good in a contempt case. Myers and Hentges deliberately refused to perform their duties except at special meetings where only such subjects as they selected would be acted upon. They prevented regular meetings of council while Fisher, Hann and Strobel blocked special meetings."

The opinion of the Court follows:

"At the hearing held before me it appeared to my satisfaction that the Borough of West Wildwood, through its elected officers, had failed to abide by the order of this Court entered as far back as 1934, and this notwithstanding the fact that the time for compliance with the order had been frequently extended in order that the City might be given every reasonable opportunity to comply.

"It did appear that prior to 1938, the city had made an attempt at compliance by putting in a chlorination plant, but it also appeared that this endeavor on the part of the city did not comply with the order aforesaid nor did it accomplish the paramount purpose of the order which was the preservation of health.

"It also appeared that in 1938 some steps were taken looking toward a compliance, but that they were abortive. I refer to the attempted bond sale and the application for W.P.A. monies.

"It is not necessary for me to point out that it is and has been possible to have complied with the Court's order, had every resort been taken to statutes in such cases made and provided, nor to add that compliance must be had even though the Borough Council confess to bankruptcy of the Borough and turn over the government of the Borough to officers of the State, as provided by statute.

"For the said disobedience, a fine of $250 will be imposed.

"Councilmen Fisher and Strobel have been in office since January of 1938 and do not deny that they knew of the Court's order. They participated in the abortive attempts to comply with the order in the year 1938.

"Hentges, Myers and Hann have been councilmen since January of 1939. They admittedly knew of the order of the Court in the latter part of April 1939. They did nothing to carry the order into effect.

"Right here I hold that the attempt on the part of Hentges and Myers to sidestep their responsibility by offering to meet with other fellow councilmen in special session does not suffice to exculpate them. They knew that their fellow councilmen would not meet in special session. It was their duty to attend regular meetings of council. They were sworn in as councilmen to do their duty as such. That duty was to attend not only special but regular meetings of council. If they were outvoted, or thought they might be, they would have done their duty in appearing and voting, no matter what the result of the vote. When they refused to attend, they were not doing their duty.

"Hann, Fisher and Strobel could have attended special meetings had they so desired, and I have no doubt but that Hentges and Myers might have agreed to a special meeting to consider sewerage matters only, but however that may be, it clearly appears that all councilmen fully aware of the Court's order, at least as to Hentges and Myers, from the latter part of April 1939, permitted disobedience thereof and actively participated in disobedience thereof, to satisfy their own particular position with respect to legislation that one side wanted passed and the other did not want. By their joint acts and failure to act they find themselves adjudged guilty of contempt.

"If the Court allows this contempt to pass unnoticed and unpunished it would be an intimation for others to do likewise with respect to the kind of an order in this or any other cause. If such a situation is allowed to exist the power of this Court and its ability to function as a protector of those whose rights, property and liberty are threatened will be gone. It is only by enforcing its orders that people recognize that they must be obeyed.

"I can see no difference in the guilt of any of the five councilmen. It was their joint refusal to meet, either in regular or special session, that resulted in nothing being done during the present year to carry out the Court's order and while it is true that Fisher and Strobel, as councilmen in 1938, did not effectively use the means at hand to have accomplished the purpose of the Court's order, yet it is the dereliction of the five councilmen in 1939 with which this Court is now concerned.

"A fine of $50 will be assessed against each of the five councilmen. The costs of the proceedings will be assessed against the Borough of West Wildwood. The five individual councilmen will have 30 days within which to pay their fines, and upon failure so to do will be confined in the County Jail at Cape May Court House.

"These sentences must not be looked upon as being a disposition of the order of this Court requiring a proper disposition of the Borough's sewerage. The original order still stands and must be obeyed and failure on the part of the Borough, through its elected officers, will result in further contempt proceedings, in which event the punishment here inflicted will not serve as the standard for any subsequent punishment."

BOOK REVIEW

Elements of Sanitation. By Edward S. Hopkins. Published by D. Van Nostrand Company, Inc. Issued in 1939. Price $4.00. Size 6 × 9: 435 pp.

This is a volume prepared by E. S. Hopkins as Editor, assisted by twelve specialists. The book is dedicated to the memory of the late Professor John H. Gregory. As the reviewer was associated closely with the Professor for many years, he has attempted to approach the task of review in the Gregorian manner.

The book is offered as a guide for the general training of college students in the fundamentals of sanitation and hygiene, as well as for training health officers and nurses. It contains twelve chapters discussing the scientific background of sanitation (5 pp.); the meaning and determination of pH (23 pp.); water and sewage disinfection (18 pp.); public water supplies (57 pp.); sewage disposal (63 pp.); stream pollution and trade waste disposal (47 pp.); refuse disposal (24 pp.); the essentials of food sanitation (42

pp.); milk sanitation (39 pp.); ventilation and air conditioning (40 pp.); swimming pool control (21 pp.); and environmental hygiene (39 pp.). As such, it comes into the field hitherto occupied by Prescott and Horwood with Sedgwick's "Principles of Sanitary Science and Public Health," and by Phelps with "Public Health Engineering," but covers a broader ground, with greater detail, and citations of actual data. As a textbook, the references given might well be supplemented by other references to various standard works and to sources from which current information may be readily obtained.

The book lacks some of the niceties of workmanship. It is unusual not to credit the authors with their respective chapters. The typographical setup could be improved, particularly in the tabular matter, which is left in a rather unfinished form. Various errors were noted in spelling and data, which should be corrected in future editions. More careful editing is indicated to meet the high standards set by the late Professor Gregory.

On pp. 109–110, the importance of preventing sludge banks in watercourses might be emphasized. The reference to the Chicago drainage canal on pages 111–114 should be entirely rewritten, as the statement is full of errors. The impression is given that the self-purification of the Illinois River is proven because excessive typhoid fever has not occurred in St. Louis. Actually, St. Louis does not receive Illinois River water, which hugs the east bank of the Mississippi River. The reference to the decision of the U. S. Supreme Court omits entirely the final cut in diversion to 1,500 c.f.s., which went into effect Jan. 1, 1939.

On p. 116, "plain settling" should be added to the subdivisions of "sedimentation tanks."

On p. 119, in discussing the material precipitated in grit chambers, "suspended" would be a better description for such than "floating."

On pp. 144–145, dealing with activated sludge, the reference given to Fowler was on M–7, not activated sludge. Acknowledgment might well be made to Hatton, Sands, and others in the United States, particularly at Chicago and Milwaukee, who developed the practical use of the process and found how to handle the excess sludge.

On p. 163, the nitrogen content of heat-dried activated sludge should be stated as 3 to 6 per cent (dry solids basis). The text might well show that an advantage of sludge for agricultural use is the humus contained, and that the largest installation of rotary heat dryers is at Milwaukee, whereas the largest heat dryer installation in the world is at the Southwest plant in Chicago.

In a book of this character, some emphasis should be put on suitable equipment for water supply and sewage disposal for small communities, camps, and institutions, with appropriate references. The place for fly control might also be discussed.

Barring these minor infirmities, the book should prove useful for instruction purposes for nurses and health officers, in the hands of an instructor who knows the field and will correct the errors, emphasize the important points, and furnish adequate references, by chapters.

LANGDON PEARSE